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DEPENDENCE OF U.S. DEFENSE SYSTEMS ON FOREIGN TECHNOLOGIES

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December 1990

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FOREWORD

This paper was prepared for the Defense Advanced Research Projects Agency (DARPA) under DARPA Project Assignment A-135, under the technical cognizance of Ms. Lisa Niesz, Office of the Director.

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ABSTRACT

This study was requested by the Defense Advanced Research Projects Agency (DARPA) to determine and quantify the extent of U.S. defense system dependence on foreign technologies. In consultation with DARPA, the study project team selected four systems to be broadly representative of technologies found in tactical programs, and studied at least one generational change, upgrade, or development program for each, for a total of eight systems and three upgrade or development programs. Missile, radar, heavy combat engine, and aircraft display systems were studied.

The study finds that foreign sourcing in these systems and programs is almost totally concentrated in four main technology areas: microelectronics components, equipment (mainly machine tools and semiconductor equipment), specialty and advanced materials, and display technologies. Some foreign sourcing resulted from decline and migration of mature technologies abroad, and eventual loss of domestic capabilities as offshore industries gained cost and scale advantages. Examples are ferrite coils, filter glass, and other specialty glass required in CRTs for aircraft displays. Among more advanced technologies, growing foreign sourcing was particularly prevalent in precision machine tools, microelectronics lithography equipment, and display technologies. Industry sources estimate that developing and qualifying fully comparable domestic alternative U.S. sources of supply would require from 6 months to 5 or 6 years under ordinary circumstances.

None of the tactical defense systems studied are found to be currently vulnerable to hostile denial, delay, or extended disruption of supply as a result of dependence on foreign technology sources. However, the erosion of U.S. production and research capabilities in the newest generations of semiconductor production equipment, precision machine tools, and high-resolution display technologies gives ground for serious concern that U.S. ability to enhance and develop future defense systems is becoming increasingly vulnerable to foreign control of these technologies.

The study finds that to restrain or reverse the increasing trend toward foreign sourcing in the four technology areas identified would require a multifaceted, holistic

effort. In addition to selected advanced research, a successful research strategy will require also that the Office of the Secretary of Defense (OSD) rationalize procurement practices, reduce the high cost and other burdens of compliance with Department of Defense procurement regulations, conduct systematic monitoring of offshore migration of key production technologies, and coordinate acquisition policies with an eye to ways of strengthening the commercial viability of industries aided by advanced research.

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GLOSSARY

AGT	advanced gas turbine (e.g., AGT-1500)
AIM	air intercept missile (e.g., AIM-120A)
AIPS	Advanced Integrated Propulsion System
AMRAAM	Advanced Medium-Range Air-to-Air Missile
APG	Designation for Airborne Fire Control Radar (e.g., APG-66)
APSP	Advanced Programmable Signal Processor
APREP	AMRAAM Producibility Enhancement Program
ASIC	application-specific integrated circuit
ASW	antisubmarine warfare
ATE	automated test equipment
AT&T	American Telephone & Telegraph
AV	Attack V/STOL (e.g., AV-8B)
AVLB	armored vehicle launched bridge
BAFO	best and final offer
biCMOS	bipolar complementary metal oxide semiconductor
CAD	computer-aided design
CAM	computer-aided manufacturing
CD	color display
CEV	combat engineers vehicle
CFD	control functional diagram
CFE	contractor-furnished equipment
CFIUS	Committee on Foreign Investment in the United States
CGA	configurable gate arrays
CIM	computer-integrated manufacturing
CMOS	complementary metal oxide semiconductor
COCOM	Coordinating Committee on Export Controls
CRT	cathode-ray tube
CVD	chemical vapor deposition
C ³ I	command, control, communications, and intelligence

DARC	Defense Acquisition Regulation Council
DARPA	Defense Advanced Research Projects Agency
DCAA	Defense Contract Audit Agency
DCAS	Defense Contract Administration Services
DESC	Defense Electronics Supply Center
DFAR	Defense Federal Acquisition Regulations
DICE	DARPA Initiative for Concurrent Engineering
DID	data item description
DINET	Defense Industrial Network
DIP	dual in-line package
DMB	Defense Manufacturing Board
DMS	Diminishing Manufacturing Sources Program
DPAS	Defense Priorities & Allocation System
DOC	Department of Commerce
DoD	Department of Defense
DoE	Department of Energy
DRAM	dynamic random access memory
DRI	directed-return items
DSB	Defense Science Board
DSM	Defense Supply Manual
DU	display units
EAR	Export Administration Regulations
ECL	emitter-coupled logic
EDS	electronic display system
EIA	Electronics Industries Association
EL	electroluminescent
EMI	electromagnetic interference
EPA	Environmental Protection Agency
EPROM	erasable programmable read-only memory
ER	established reliability
ESPRIT	European cooperative research program
Est	Estimated
EUREKA	European cooperative program in HDTV and other research
FAR	Federal Acquisition Regulations
FASAC	Foreign Applied Sciences Assessment Center (SAIC)

FCR	fire control radar
FET	field effect transistor
FFF	form-fit-function
FLIR	forward looking infrared
FR	France
FRG	Federal Republic of Germany
FSD	full-scale development
GaAs	gallium arsenide
GAO	General Accounting Office
GE	General Electric
GFE	government-furnished equipment
GPC	Government Procurement Committee
HDS	high-definition systems
HDTV	high-definition television
HFMP	Heavy Force Modernization program
HP	Hewlett-Packard
HPM	head positioning mechanism
HSI	horizontal situation indicator
HTPB	hydroxy-terminated polybutadiene
HUD	head-up display
IBM	International Business Machines Corporation
IC	integrated circuit
ICE	Integrated Circuit Engineering Corporation
IDA	Institute for Defense Analyses
IEPG	Independent European Program Group
IMIP	Industrial Modernization Incentives Program
IOC	initial operating capability
IPDI	isophorone diisocyanate
IPP	industrial preparedness planning
IR	infrared
IR&D	independent research & development
ISA	International Standardization Agreement
ITAR	International Traffic in Arms Regulations

JA	Japan
JAN	Joint Army Navy Standard
JANS	Space-class JAN devices
JANTXV	Exceptionally rigorously tested and inspected JAN devices
JTIDS	Joint Tactical Information Data System
JSPO	Joint-service system program office
Kyocera	Kyoto Ceramics Corp.
LCD	liquid crystal display
LED	light-emitting diode
LPCVD	low-pressure chemical vapor deposition
LRAACA	long-range air antisubmarine warfare capability aircraft
LRU	line-replaceable unit
LSI	large-scale integration
LTS	laser target simulator; launch tracking station; linearity test set
LV	land vehicle (e.g., LV100)
M1A1	designation for Abrams tank
MAPI	Machinery and Allied Products Institute
MANTECH	Manufacturing Technology (program)
MBT	main battle tank
MDI	multipurpose display indicator
MDRI	multipurpose display repeater indicator
MILSPEC	military specification
MILSTD	military standard
MIM	metal-insulator-metal
MITI	Ministry of International Trade and Industry (Japan)
MIMIC	DARPA microwave and millimeter-wave IC program
MMIC	monolithic microwave IC
MMW	millimeter wave (radio)
MOS	metal oxide semiconductor
MOU	memorandum of understanding
MPCD	multipurpose color display
MTU	Motoren-und-Turbinen Union, West Germany

N/A	not available
NAC	Naval Avionics Center (Indianapolis, IN)
NASA	National Aeronautics & Space Administration
NATO	North Atlantic Treaty Organization
NAVAIR	Naval Air Systems Command
NC	numerically controlled
NEC	Nippon Electric Corporation
NIST	National Institute of Standards and Technology
NMOS	N-channel metal oxide semiconductor
NMTBA	National Machine Tool Builders Association
NRE	nonrecurrent engineering
NSF	National Science Foundation
NSN	National Stock Number
NSP	nonstandard part
NTT	Nippon Telegraph and Telephone
NVG	night vision goggle
OEM	original equipment manufacturer
OPEC	Organization of Petroleum Exporting Countries
OSD	Office of the Secretary of Defense
OTA	Office of Technology Assessment
OUSDA	Office of the Under Secretary of Defense for Acquisition
PCC	plastic chip carrier
PECVD	plasma-enhanced chemical vapor deposition
PIN	p-intermediate-n
PMC	polymer matrix composite
PMOS	p-channel metal oxide semiconductor
ppm	parts per million
PPSL	provisional parts supply list
P ³ I	preplanned product improvement
QA	quality assurance
QC	quality control
QML	qualified manufacturers list
QPL	qualified parts/products list

R&D	research and development
RAM	random-access memory
RAND	The Rand Corporation
RCV	tank recovery vehicle
RF	radio frequency
ROM	read-only memory
R&T	research and technology
RTP	request for technical proposal
S&T	Science and Technology
SAF	safe-arm-fire
SAIC	Science Applications International Corporation
SAR	synthetic aperture radar
SCD	specification or source control drawing
SEM	(Navy) standard electronic module
SEMI	Semiconductor Equipment and Materials International
SIA	Semiconductor Industry Association
SIC	Standard Industrial Classification
SID	Society of Information Displays
SMD	standard military drawing
SPC	statistical process control
SPO	System Program (or Project) Office (or Officer)
STANAG	NATO Standardization Agreement
SRU	shop replaceable unit
Switz	Switzerland
TACOM	Tank-Automotive Command
TASC	The Analytic Sciences Corporation
TBD	to be determined
TFT	thin-film transistor
TI	Texas Instruments
TQM	total quality management
TTL	transistor-transistor logic
TME	test maintenance equipment
U.K.	United Kingdom
U.S.	United States

USD(A)	Under Secretary of Defense for Acquisition
USSR	Union of Soviet Socialist Republics
VE	Value Engineering (program)
VHSIC	very-high-speed integrated circuit
VLSI	very-large-scale integration
V/STOL	vertical/short take-off and landing
WJ	Watkins-Johnson

EXECUTIVE SUMMARY

The Defense Advanced Research Projects Agency (DARPA) requested the Institute for Defense Analyses (IDA) to study selected defense systems to determine and quantify the extent of their dependence on foreign technology. Four types of defense systems were chosen: cockpit displays, aircraft radar, air-to-air missiles, and heavy combat vehicle engines. The selection criteria aimed at acquiring a broad representation of system types; they also emphasized selection of systems that evolved over time in order to determine if the extent of dependence on foreign technology changes as system technologies evolve. Study teams looked at both current and older versions of each system, and at the latest upgrade or development programs, for a total of eight systems and three upgrade or development programs.

A. FINDINGS

1. Extent of Foreign Sourcing

The study found no case in which foreign technology sourcing appears to threaten *imminent* risk of supply disruption. However, it did find several technologies now heavily dependent on foreign sources in which reconstitution of U.S. production capabilities could face delays of up to several years if supply from foreign sources were threatened with denial or extended disruption. The study also identified growth of foreign sourcing in four technology areas where further erosion of U.S. production and technology capabilities could jeopardize near- or long-term DoD abilities to assure supplies for defense systems. One obstacle to sourcing identification and monitoring is the lack of a ready and reliable source of information on the ownership and control of U.S.-based defense suppliers. As a result, the the great majority of study findings concentrate on sourcing from offshore.

Found to present the most risk in the systems studied is the foreign sourcing of production and technology capabilities in (1) microelectronic devices, (2) certain machine tools and other means of production such as photolithography for microelectronics fabrication, (3) certain advanced and specialty materials (ceramic packages, silicon, gallium arsenide, ferrite coils, filter glass), and (4) display technologies (high-resolution systems).

These U.S. industries have undergone continued decline, which now shows up in high percentages of foreign sourcing in defense systems.

Especially in microelectronic devices and production equipment, the trends found are toward steadily increased foreign sourcing. The study found instances of 80-100 percent dependence on foreign sources for machine tools used by certain prime and primary subsystem contractors. The percentage of foreign sourcing was highest for more sophisticated types of machine tools, with a particular growth of concentration in sourcing of numerically controlled machine tools from Japan. In emerging display technologies, much lower U.S. levels of R&D compared with those of Japan and Europe, as well as the rising concentration of production capabilities offshore, create growing potentials for defense system supply risks. However, the highest concentrations of sourcing in a single country or source are found in defense items based on mature or older technologies in which U.S. capabilities have eroded, such as specialty glass and optical items for displays.

Many DoD procurement requirements, such as military standards or "Buy American" provisions, divert sourcing choices from consideration of "the best technologies," especially at the prime and principle subcontractor levels. The extent of foreign sourcing is found to increase as tracking moves to lower and lower subcontractor levels where procurement regulations have more limited effect. Lack of data systems to track foreign sourcing further complicates the process of source identification. At a system level, contractor sourcing of production equipment provides the most meaningful evidence on changes in defense system use of foreign technology. Because the sourcing of production equipment purchases is least subject to DoD procurement regulations or limitations aimed at objectives other than acquiring the best technologies, some of the highest levels of foreign dependence are found in production equipment. Even so, most production equipment sourcing is not as yet heavily concentrated in single countries or suppliers.

2. Reasons for Foreign Sourcing of Technologies*

Among the main reasons for sourcing dependent on foreign technologies, the study found just two major cases clearly based on *unique* foreign technologies: flat panel color

* For each example of foreign sourcing motivated by foreign technology advantages, the study found many more cases where foreign procurement was based on cost savings or other nontechnology advantages. Thus it was necessary to investigate reasons for each foreign sourcing to single out only those based on foreign technology advantages.

displays and photolithography equipment for microelectronics manufacture. Much more common were instances of foreign sourcing of products dependent on *older or maturing* technologies. This pattern results from long system gestation, often taking up to 10 years or more from initial design through final approval; thus even the newest systems contain technologies that are dated or old when finally fielded. Some such technologies were once well established in the United States but were lost as offshore producers gained cost, volume, market-share, and gradually technology advantages over U.S. producers, most of which consequently left the business. At least four major cases involve dependence on just one or a few foreign sources. Such technologies include semiconductor materials such as ceramic packaging and semiconductor-grade gallium arsenide, as well as specialty-material products such as ferrite deflection coils, glass tubes, and optical materials required for displays. The other cases of concentrated foreign sourcing identified by the study are attributable to cost, quality, service, or other foreign advantages not related to technology.

3. Effects of Acquisition Policies

In analyzing reasons for foreign sourcing, many contractors stressed the adverse effects of DoD acquisition policies and practices. Most fundamental is the problem of conflicting sets of acquisition laws and regulations, some encouraging and others discouraging use of foreign sources. More than 20 categories of problems associated with DoD procurement policies were raised by contractors interviewed. Contractors maintain that high, and arguably excessive, costs and special conditions for defense procurements reduce the number and competitiveness of domestic suppliers, contributing to increased reliance on foreign sources. A prime example cited is government assertion of rights to proprietary data used for soliciting second sources to compete with initial developers. In microelectronics, a pending decision whether or not to authorize the addition of overseas locations to the Qualified Manufacturers List (certifying as MILSTD all defense products from those facilities) could result in greatly increased offshore procurement of MILSTD devices.

B. CONCLUSIONS AND RECOMMENDATIONS

The major conclusions and recommendations of this study are the following:

1. Research Priorities

DARPA research priorities are intended to emphasize *advanced technologies* where U.S. leadership is pivotal for future defense system development. Most relevant to this emphasis are study findings of high concentrations of foreign sourcing in microelectronics production equipment, high-resolution systems, machine tools and other precision production equipment used in defense applications, and advanced materials. Because of their prospective importance for the development of future defense systems, these are technologies in which the growing concentration of foreign sourcing appears to warrant continued and possibly increased DARPA research support. Specifically indicated would be: (1) continued research efforts in semiconductor packaging and assembly technologies; (2) a continued and possibly more concerted and coordinated program in advanced micro-electronic lithography; (3) new research in support of advanced numerically controlled and robotic manufacturing technologies; and (4) continued funding for high-resolution information displays.

Cases where foreign sources are approaching an exclusive or predominant supply position in established or aging technologies correspond less well to DARPA's traditional priorities. In the absence of compelling indications that supply of the products of such technologies may be subject to imminent denial or disruption, dependence issues raised by these cases are more appropriately addressed by those closer to the procurement and industrial base management processes. In the procurement context tradeoffs between possible foreign cost, quality, and other procurement advantages on the one hand, and the risks of foreign dependence on the other, can be weighed more appropriately than in a research priority context. Where procurement authorities judge the supply risks of foreign dependence to be very high, and procurement measures or funding of new production capabilities will not solve the problem, some research aimed at restoring a U.S. technology base may be justified. In examining the more mature defense technologies which lack an adequate U.S. supplier base but are required in growing volumes by defense systems, the study found that specialty ferrite, glass tubes, and optical products used in displays are potential candidates for such research. However, the study found no imminent risk of denial or disruption in any of these items at present.

2. Complementary Assessment Needs

The report finds that a study methodology based on assessment of *fielded systems* more easily provides hindsight into the supply state of *aging* technologies than foresight on

trends in *advanced* technologies. To shape a research strategy based on assessment of trends in new and emerging technologies requires in addition to system-based studies a more systematic monitoring and assessment of technologies that are forthcoming but not yet used in or even designed into defense systems. DARPA's strategy planning would therefore benefit from a broad survey and monitoring of global trends in critical defense technology capabilities on a more systematic and comprehensive basis than now available. Related is the need for a database system to provide prompt, reliable identification of foreign ownership and control of U.S. defense industries and technologies. While risks of sudden denial or disruption of supply from U.S.-based but foreign-owned facilities are more readily and easily subject to U.S. control than those from foreign-based sources, given time, foreign owners could disable or dismantle U.S.-based facilities.

3. Research Strategy

Some erosion of U.S. defense technologies is attributable to attrition of the commercial market for the products of these technologies, compounded by costs and inconsistencies of DoD acquisition policies and practices. Benefits of defense advanced research can be lost if firms in the participating industries lose market viability, lack the financial resources to remain competitive, or undergo foreign takeover. Thus DARPA's research strategy should include attention to this *viability* aspect of the U.S. technology base. To develop this strategy, DARPA should pursue a four-step process: (1) closely follow trends in the global leadership and migration of key defense technologies; (2) monitor trends toward greater offshore sourcing of defense production equipment; (3) use monitoring results to develop research priorities to assure domestic capabilities in technologies most critical for defense; and (4) coordinate these priorities with DoD acquisition policy makers to align both acquisition and research priorities in support of reducing foreign supply vulnerability.

4. Supporting Policies: A Holistic Approach

The IDA study finds several pivotal defense technologies that are progressively moving offshore, and that create growing risks of vulnerabilities in the future development of defense systems. While measures needed to reduce these risks differ somewhat from system to system among those studied, in all cases the solution requires a holistic effort that includes not only strengthened research but also additional monitoring and assessment, and a more supportive set of acquisition policies.

Since DARPA's research impact depends on the continued financial strength and market viability of its defense contractors, it should seek DoD policies that will strengthen defense supplier market viability. For example, USD(A) should provide incentives for system vendors to cooperate more closely with U.S. machine tool manufacturers in improving their capabilities for supplying defense industries, drawing on techniques that SEMATECH is using to encourage greater cooperation by semiconductor producers with the U.S. semiconductor production equipment industry. It might also provide incentives to stimulate greater defense contractor R&D and investment in development of U.S. production equipment. In addition, DARPA should also explore with DoD officials the potential for encouraging more IR&D funds to be spent on improvement of manufacturing processes, machine tools, and other manufacturing and process equipment.

Acquisition policies can do much to strengthen the market base and expand R&D and investment in priority defense technologies. In addition, OSD, with assistance from DARPA, should develop policy guidance to eliminate present acquisition policies and practices that conflict with DARPA efforts to strengthen critical defense technologies. DARPA should also encourage USD(A) to review and modify those acquisition policies and practices that are most subject to contractor complaints about undue cost and burden, and to seek legislative changes where required.

I. INTRODUCTION

A. PURPOSE OF THE STUDY

The Institute for Defense Analyses (IDA) conducted this study at the request of the Defense Advanced Research Projects Agency (DARPA) under Project Assignment A-135, "Defense System Dependence on Foreign Technologies." The purposes of this study are: (1) to determine technology areas in which U.S. defense systems depend on foreign sources, and (2) to provide factual and, where possible, quantitative measures of foreign dependence. See Appendix A, Annex I, for the text of the Project Assignment agreement.¹

The need for an empirical basis for considering the importance of foreign sourcing was clearly set forth in GAO testimony before the House Government Operations Committee on July 18, 1989, by Frank Conahan, Chief of National Security and International Affairs of the General Accounting Office. He is reported by *Aerospace Daily* as saying:²

- There is no solid way to measure the extent of the Pentagon's dependence on foreign sources in critical areas, despite a wealth of anecdotal evidence that the problem exists.
- The Pentagon and other government agencies have been trying to collect and analyze industrial base data systematically for some time, but only in an "on-again, off-again" way.
- Reliance on ad hoc data collection, which is based on varying methodologies, puts DoD in a reactive role and limits its ability to identify trends in critical industrial sectors.
- This approach is "inefficient and of limited effectiveness" because it offers only a little insight into foreign dependencies at the subcomponent level, and doesn't help identify acquisition strategies or shorten DoD's decision-making process.

¹ The IDA study constitutes one part of a broader study to which other organizations have contributed, including DARPA, the Rand Corporation, the Science Applications International Corporation (SAIC), and the Analytic Sciences Corporation (TASC).

² *Aerospace Daily*, July 20, 1989, pp. 117-118.

B. DEFINITIONS

The study required working definitions for several key terms, including "foreign" and "dependence."

1. Foreign

Because of growing "globalization" of the defense and high-technology markets,³ including increasing numbers of mergers and acquisitions, it is often difficult to define or determine the country origin of some of the systems and components procured by DoD. DoD is increasingly faced with deciding how to treat (a) firms or facilities located in the United States but having foreign ownership or control, (b) firms or facilities physically located in foreign countries but owned or controlled by U.S. nationals, and (c) joint ventures between U.S. and foreign firms located either here or abroad.⁴ We chose to use a broad definition of "foreign source" in this study, which includes foreign-owned facilities located outside the United States and Canada, U.S.-owned facilities outside the United States and Canada, and foreign-owned facilities located in the United States and Canada. In practice, it often proved extremely difficult and time consuming to make these determinations. A last resort was often to contact firms directly to determine their ownership and plant locations. Organizing study data in this manner allows consideration of differing implications for U.S. security. The study applies this term without any prejudgment that "foreign" sourcing automatically connotes vulnerability or risk, any more than domestic sourcing does. These are judgments which can only be drawn from assessment of the applicable circumstances.

2. Dependence

Unlike "sourcing," which either exists or does not, the terms "reliance" and "dependence" form a continuum from very limited sourcing to total dependence on a single source. Vulnerability in a foreign context is a function of dependence, of political, military, and economic relations with source countries, and of such factors as proximity, technology options, and alternatives for responding to possible supply disruptions. These factors may differ by source country, type of technology involved, and risk scenario being assessed.

³ See *The U.S. Aerospace Industry and the Trend Toward Internationalization*, Washington, D.C.: Aerospace Industries Association of America, Inc., March 1988.

⁴ See *Holding the Edge: Maintaining the Defense Technology Base*, Office of Technology Assessment, OTA-ISC-420, April 1989, pp. 179-182.

Thus, the choice of criteria to distinguish between dependence and vulnerability becomes a matter of judging the applicable situation rather than of applying known or fixed objective parameters to a particular situation. Instead of attempting to formulate and apply a general definition of vulnerability, the study findings emphasize the facts, circumstances, and reasons involved in current sourcing decisions, as well as the alternatives for responding to possible disruptions.⁵

C. METHODOLOGY

1. Focus of the Study; Criteria for System Selection

IDA was tasked to assess foreign sourcing in a variety of selected types of weapon systems. The need to *quantify the scope and significance* of dependence and the need to choose systems as broadly representative of dependence issues as possible were also emphasized in the tasking. In addition, the study *emphasizes new or emerging technologies* and seeks to *ascertain trends* in dependence. The 3-month time constraint for conducting the study necessitated limiting data collection to a small sample of defense systems. This limitation increased the importance of selecting systems that would (a) be representative of critical technology areas, (b) cover technology currently used in important defense systems which will also have significant roles in the future, and (c) include systems procured by the different armed services. In determining the number and types of systems to be studied within the available time and resources, the project team chose systems that would:

- Be multigenerational, involving *at least* one major upgrade to permit examination of any *trends* in foreign technology sourcing in the system over time
- Include current technologies, by choosing those with a recent upgrade entering into initial low-level production, or into final stages of prototyping as recently as possible, in order to include the *latest fielded technologies*
- Involve minimal overlapping or duplication with other selected systems, but include a multiplicity and diversity of technologies that could be considered
- Include some dual-use technologies, anticipating that defense systems will be increasingly influenced by technologies developing initially in civilian applications.

⁵ Appendix A, Annex II, contains a list of vulnerability factors and an analytical structure for assessing risks from foreign sourcing.

Because of DARPA's charter for research in *advanced* technology, this study chose systems with new generations just entering initial production. At that point they are most likely to incorporate newer technologies of greater interest to DARPA, yet at the same time be based on fairly definitive decisions on sourcing. Fielded defense systems frequently contain older and even obsolete technology for such reasons as: (1) long gestation periods from design through fielding of defense systems, and (2) program managers' reluctance to include in their system design newer technologies which they consider insufficiently proven. By contrast, systems still in final development or prototyping are likely to incorporate components produced on a piece basis or purchased from sources that may not be used in actual production. During the study, we also found that we could identify trends in sourcing of newer technologies by giving special attention to technology insertion programs, quality and productivity upgrade efforts, and discussions with design engineers working on upgrades and technologies beyond those yet in production.

2. Systems Selected for Study

On the basis of these criteria and some initial suggestions from DARPA, the project team selected the following systems for analysis:

- **Aircraft Displays: AV-8B, F-18, and P-7.** Displays found in these aircraft are the result of many generations of development and are subject to keen international competition. Aircraft displays represent a dual-use technology--one that may potentially be driven by commercial developments. Because of the many possible applications of this technology, cockpit displays offer a cross section of current and future display technology. Information displays are found in sea, land, and air systems, thereby potentially permitting broader view foreign sourcing findings than possible with other systems considered in the study.
- **Aircraft Radar: APG-66 and APG-68.** The APG-66 and APG-68 radars, used in all U.S. and most foreign F-16's, are considered among the most successful fire control radars in the world. They provide a window on microelectronic technologies, increasingly important in contemporary weapons. The APG-68 is the direct linear successor to the APG-66.
- **Air-to-Air Missiles: AIM-7 (Sparrow) and AIM-120 (AMRAAM).** The Advanced Medium-Range Air-to-Air Missile (AMRAAM) is intended to replace the Sparrow eventually as the nation's main medium-range intercept weapon. It is actually a markedly more capable missile rather than a new generation of Sparrow, since it is designed for more ambitious all-weather launch-and-leave missions. Together these missiles illustrate electronic, mechanical/structural, and chemical technology trends in two air-to-air systems critical for both Navy and Air Force programs.

- **Heavy Combat Vehicle Engines: M1A1 and AIPS.** The heavy combat vehicle engine was selected because propulsion system alternatives are currently under consideration under the Advanced Integrated Propulsion System (AIPS) program. The significance of including an engine system for study includes: (a) broad use of diesel and turbine engines throughout the military; (b) representation of a major Army and Marine Corps system; and (c) the prospect of looking at technology sourcing choices at late planning stages under the AIPS.

3. Information Collection and Assessment

A central challenge of this study is to identify the *extent* and *significance* of U.S. defense system dependence on foreign technology, and to *quantify* these factors to the extent possible. This challenge in turn presented several hurdles in developing the approach for conducting this study.

a. "Sampling" Defense Systems

Each system selected is composed of many subsystems, components, and parts that are found widely in similar systems. To increase the scope of the sample, the study also examined generational changes, upgrades, and major enhancement programs, thus in effect including 10 systems and 2 development programs rather than just 4 systems.

One limitation of the study is that it is not feasible within the constraints of time and data obtainable to trace all parts down the entire length of the supply chain. Thus, in drawing samples of parts to be tracked, instances of foreign sourcing will certainly have been missed.

b. Identifying Foreign Technology Sourcing

The current requirements for military system program or project offices (SPOs) to know the extent of foreign sourcing in their system are limited. The multilayered structure of the procurement process and the prodigious numbers of parts that go into complex systems at subtier levels limit knowledge of foreign sourcing by both SPOs and prime contractors. These difficulties increase the further one moves down the levels of suppliers. SPOs and primes may attempt to assure that certain critical components and parts are not foreign-sourced by insisting that they conform to military standards that control terms of sourcing (e.g., strategic systems, classified programs, and certain JAN⁶ microelectronic parts incorporate source-control conditions). However, many other components and parts

⁶ Joint Army-Navy Standards.

may not be subject to such controls, or may be sourced under waivers from these standards.

Because prime contractors procure subsystems, subassemblies, components, and parts from subtier suppliers, which in turn purchase materials or parts from suppliers and distributors, many layers need to be tracked to determine with certainty the source of parts and materials, particularly those within subsystems and subassemblies. In a 1985 assessment of defense dependence on foreign microelectronics devices, an IDA study found it necessary to trace parts back through several subtier supplier levels to ascertain whether foreign materials, parts, or processing were involved.⁷

For this study the matter is even more complex because the objective is to determine not the sourcing of parts and processing, but of *technology*. This includes sourcing of equipment (embodied technology) for design, production, and testing, as well as process rights and operational know-how. Foreign sourcing of parts or components may be indicative, but does not by itself establish foreign sourcing of technology. Nor does production in facilities located in the United States prove there is no foreign sourcing. Even if a material, component, part, or subassembly were produced entirely in the United States, and entirely from materials produced in the United States, its production might still be dependent on *foreign equipment or process rights*. This possibility is not hypothetical. For example, as leadership in certain microelectronic production technology has progressively migrated offshore, e.g., as it has to Japan in photolithography for microelectronics, the prospect of dependence on foreign production technology increasingly has become reality.

In practice, determining foreign technology sourcing has meant that the four system teams had to follow an elaborate data collection process taking them down several tiers in the procurement chain. Full details of the effort required are provided in the individual system studies (Appendix B). In general, the major steps of investigation for each system included:

1. Visits to SPOs to determine known instances of foreign sourcing of procurement and/or technology, prime, second source and main subtier contractors, contract terms, and important military standards which affect the systems.

⁷ R.H. Van Atta, E.H. Heginbotham, F.R. Frank, A.J. Perrella, and A.W. Hull, *Technical Assessment of U.S. Electronics Dependency*, Institute for Defense Analyses, IDA Paper P-1841, November 1985.

2. Visits to prime contractors to obtain lists of parts and suppliers actually being used in the system, to identify instances known to primes of foreign sourcing, to identify foreign equipment or foreign processes used by primes in their system production and assembly; and to learn why foreign sourcing is used, and what the importance of the foreign-sourced items, processes, or equipment is to the system.
3. Visits to subcontractors to determine what items or parts these subcontractors obtain from distributors, wholesalers, or other contractors. These visits, as well as visits to the prime contractors, proved helpful in determining what difficulties system production would encounter if foreign sourcing were interrupted, and what costs, obstacles, and delays would be encountered in developing alternative domestic sources.
4. Visits to other sources, including defense and private sector establishments, were helpful in understanding data and views obtained from various levels of the system production chain. These include the Naval Avionics Center (NAC) and the Defense Electronics Supply Center (DESC) of the Defense Logistics Agency.

c. Nontechnical Factors That Reduce Dependence

Many DoD policies and procedures affect the use of foreign technology. We have noted cases where such laws, policies, and regulations have been applied to the systems analyzed in this study, and we have considered their influence in analyzing the significance of the foreign sourcing identified.

II. FINDINGS

The remainder of this report provides a consolidation and overview based on the findings, conclusions, and recommendations of the four system studies, supplemented by evidence from other studies and reports as appropriate. Annexes I through IV of Appendix B provide executive summaries and the full texts of the four system studies.

A. FOREIGN SOURCING OF DEFENSE SYSTEM TECHNOLOGY

1. General Findings on Technology Sourcing and Dependence

Study findings provide data on instances of and reasons for foreign sourcing. Additionally, the study provides insights into the advantages and shortcomings of relying on sourcing of weapon systems as a means of assessing foreign technology dependence.

a. Findings on Foreign Technology

The following findings are presented roughly in order of their significance regarding foreign technology sourcing in the four systems studied.

1. None of the four systems studied currently appears vulnerable to imminent disruption, denial, or nonavailability of technology from foreign sources.
2. Four key technology areas exhibit a trend toward offshore sources becoming dominant or potentially exclusive suppliers. These trends raise concerns about circumstances in which the United States might become vulnerable.

Individual system studies (Appendix B) found such trends in: microelectronic device production, including packaging, assembly, and (to a lesser extent) fabrication of both discretes and microcircuits; advanced materials, including ceramic packaging and gallium arsenide; production equipment, including machine tools and lithography equipment; and flat panel display technology.

3. In several areas of "mature" technology, supply is dominated by one or a few foreign sources. The United States has lost its supply capability and associated know-how as foreign suppliers have gained market dominance.

These areas include (1) several optical technologies used in CRT and flat panel displays (filter glass, optical filters, glass bulbs, and enhancement filters), and several material technologies, including (2) molded ferrite deflector yokes--required for CRT displays, (3) merchant semiconductor grade silicon, and (4) ceramic packaging for integrated circuits (ICs). Once these capabilities are lost, extended periods would often be needed to restore a domestic capability if it were required. For example, a small number of Japanese and German suppliers dominate sourcing of the first two items listed; defense contractors estimate that as much as 4 to 6 years might be needed to develop alternative U.S. sources because of special skills and tooling, *if fully equivalent domestic sources were required.*

In these areas, foreign sourcing grew not because of a technology lag but because U.S. supply capability dwindled or disappeared as markets abroad grew rapidly, and as foreign competitors gained while U.S. suppliers lost market share and profitability. Restoration of U.S. capability will involve not just regaining the requisite technical and production capabilities; a more difficult obstacle is achieving a viable market position, especially in slow-growth or declining industries. Creating a production capability for defense purposes without a profitable and viable commercial market share becomes a costly and risky proposition.

4. Studies also identify three cases of dependence on raw-material sources that are heavily concentrated geographically. Although the source of supply owes nothing to technological advantage, at least one material could at some time present a significant future supply problem. To develop a substitute would pose a technology challenge.

A case in point is chromium from South Africa required for the AMRAAM. South Africa is the sole source of this material used in the missile, and the source of at least 75 percent of the total U.S. supply.⁸ For this and two other materials--titanium (available from many other sources) and a special magnesite sand required for fabrication of the AMRAAM radome--stockpiling may be the most economic solution barring an extremely prolonged disruption. In the latter case, research to develop alternative materials might be required.

⁸ *Strategic Materials: Technologies to Reduce U.S. Import Vulnerability*, Office of Technology Assessment, Report OTA-ITE-248, May 1985, p. 285.

b. Reasons for Foreign Sourcing

As noted in the introduction, extensive foreign sourcing of a part, a component, or even an equipment need not constitute evidence of dependence on foreign *technology*. For this reason, it is necessary for system studies to determine the reasons for foreign sourcing.

1. Analysis of four systems finds only two cases of sourcing based mainly on unique foreign technology advantages. These are flat panel color displays and lithography equipment from Japan.

As the study of aircraft displays (Appendix B, Annex I) indicates, at the R&D level the differences in national leadership and commitment to high-resolution systems are unfavorable to the United States and do not bode well for future U.S. technology leadership. The U.S. effort is seriously underfunded compared to those of Europe and Japan.⁹

Japan is the most cost-effective supplier of cutting-edge lithography equipment. This is due to the strength of its investments in the technology, accentuated by the decline of American competitors. The five integrated-circuit manufacturers interviewed for the radar study all indicate a high degree of reliance on Japanese-sourced lithography equipment. In the worldwide commercial market, Nikon and Canon of Japan account in 1989 for nearly 80 percent of commercial sales of lithography equipment.¹⁰ Lithography technology is a key driver in advances in microelectronics production capability at decreasing levels of miniaturization in circuit feature size. Thus, as defense applications move toward denser circuit configurations requiring smaller feature sizes, prospects that they will be produced by using foreign-sourced lithographic equipment increase.

The lithography industry in the United States is in peril. It was feared that the microelectronics division of one of the two remaining American suppliers of state-of-the-art lithography equipment--Perkin-Elmer--would be sold to a foreign firm, but an 11th-hour purchase by the U.S.-based Silicon Valley Group was organized. The only other U.S. manufacturer of advanced lithographic equipment is the General Signal Corporation, which

⁹ See Government of Japan, Ministry of International Trade and Industry, Industrial Structure Council, Information Industry Committee, Long Term Outlook Subcommittee, *A Vision of the Information Industry in the Year 2000* (Tokyo: 19 June 1987). See also Japan LCD Production Forecast in *Japanese Developments in High Definition Television*, Austin, TX: TechSearch International, September, 1989.

¹⁰ Lithography equipment accounts for the largest percentage of the equipment cost for a new fabrication line, ranging from 30 to 50 percent of the total "front-end" capital costs.

makes the GCA and Ultratech step-and-repeat lithographic equipment. The competitive position of this firm is precarious.

2. The study finds at least four instances where foreign sources appear to have sufficient technological advantage that U.S. defense contractors point to this technology lead as a main reason for their sourcing choice.

Where contractors claimed a foreign source to be a unique supplier or to have a quality advantage not available in the United States, we considered such instances as advantages in advanced technology. Instances included contractors which relied heavily on particular types of precision and numerically controlled machine tools, mainly from Japan; phosphors for flat panel displays, from Japan; optical filters and enhancement filters for CRT displays, from Germany and Japan; and special filter glass for CRT displays, from Japan.

Study teams obtained conflicting views as to whether the U.S. machine tool industry can supply equipment that can match and sustain the high tolerances claimed for Japanese and some European equipment. Numerous instances of preference for foreign sourcing were also at least partly explained by better foreign delivery times, after-sale support, and terms of sale (see Appendix B, Annex IV). Contractor estimates of 3 to 5 years for the United States to achieve comparable capabilities suggest at minimum that U.S. industry has an image problem if not a technological one.

3. The study identifies cases in which some foreign quality, design, or manufacturing advantages are claimed.

Study teams found it difficult to determine whether such advantages stem from non-technical factors such as better management, or whether superior engineering, design, or manufacturing techniques should be interpreted as technology advantages. In any event, whatever technology advantages may exist in these cases appear minor or marginal, and not a major challenge for technological research.

Defense contractors claim that developing comparable domestic source quality could take 2 or more years in some of these cases, including time required for development work and domestic source qualification. Addressing such a challenge may be more appropriate for the mobilization planner than for the DARPA manager. However, given the general lag in U.S. manufacturing and process efficiency, defense research could usefully focus on improving production technologies in order to overcome foreign advantages where retaining a defense capability is important. Examples of such cases include foreign

sourcing of semiconductors, a heat exchange unit (recuperator) in a developmental gas turbine engine for heavy combat vehicles, and ferrite cores, glass filters, and filter glass.

4. Foreign technology advantage in some cases is found to be based mainly on erosion of U.S. production capabilities and market base in "mature" or aging technologies.

Various components for CRTs, procured predominantly from a few foreign sources, are a case in point. For such currently high-volume items, if a threat of denial from present foreign sources should arise, the research required to determine the cost-benefit of investing in domestic low-volume production capabilities may be justified. Over the next few years, however, defense requirements for these items are likely to decrease in quantity as flat panel displays play a growing role in defense systems.

2. Determining Foreign Technology Sourcing

Study efforts to identify and quantify what technology is foreign sourced, as well as where it is sourced and why, provide valuable insight into broader problems of tracking and quantifying foreign technology dependence.

1. The study found no defense database broadly useful in identifying foreign sourcing in the four systems studied.

The Defense Industrial Network (DINET) system, managed by the Office of Defense Industrial Base Assessment, was of limited use for study assessments because, while broadly based, it only covers sourcing of parts and systems *contracted for directly by DoD*. To date, DINET does not account for part and component procurements by prime contractors or subcontractors, nor does the Defense Electronics Supply Center. The Naval Avionics Center has a good tracking system; it covers avionics but none of the subsystems examined by these studies.

2. DoD ability to monitor and control sourcing decreases below the prime contractor level, while the extent of foreign sourcing increases substantially at lower tiers in the procurement process.

Prime contractors can be required to assure that a system or assembly is procured from domestic sources at the first supplier level. However, neither primes nor program managers are concerned to record whether the system or assembly contains components, parts, or materials procured offshore, particularly if the first-level source is domestic.

3. Project managers have many ways to prevent foreign sourcing *at the prime level and upper subtiers* of the procurement chain if they choose.

A system-based study understates the extent of foreign technology sourcing that would occur if such limits were not used by managers.

A few examples of those identified are:

- **Buy-American provisions**
- **Sourcing limitations dictated by classified programs, and special security precautions in strategic weapons and other sensitive programs**
- **Military standards requirements for production in the United States**
- **Contract provisions, either incorporating FAR provisions (see Appendix B), or originated by SPO requests, or mandated by prime contractors**

Use of such measures in procurement varies widely from system to system. As a result, foreign technology sourcing found in defense systems can often differ widely from patterns of foreign technology dependence found in commercial markets. In addition, in many programs SPOs lack means for learning easily about foreign technologies that might benefit their systems.

- 4. Evaluating the use of foreign technologies by monitoring fielded systems does not adequately address leading-edge technology. However, a system-based study does provide broadly useful insights on dependence resulting from foreign sourcing of production technologies.**

The list of technology dependences covered by these studies of fielded tactical systems is abbreviated partly because of the limited sample size.

- 5. Only in the area of equipment acquisition is the procurement system free of regulations imposing source requirements on procurement choices.**

Weakening of equipment industries is one of the early indicators of declining international competitiveness. Decline in the U.S. machine tool, construction, and semiconductor equipment industries provides cases in point. Findings regarding equipment sourcing appear to be some of the more important of those produced by this study.

- 6. There is no easy way to assess global trends in key defense technologies. A comprehensive information system is needed to provide unclassified and classified assessments of shifts in comparative national strengths in key defense technologies, to supplement data available from system studies.**

Many government and private sources assess global technology trends in either specific or diverse fields. None produces regular and comprehensive systematic assessments. Project Socrates appeared closest to meeting this need. It had long-range goals of

tracking most critical technologies and of being able to produce an unclassified product for use by civilian industries. However, to realize its goals would require considerable staffing to collect and analyze data and to sanitize what is produced for public use. It lacks the support to become a major source for current comprehensive assessments in a form adequate for DARPA needs.

3. System Findings

a. Aircraft Displays

This study surveys the cockpit displays for three aircraft--the Navy Fighter-Attack F/A-18 (Hornet), the Navy Attack V/STOL AV-8B (Harrier), and the Navy Patrol P-7, for which cockpit displays are still under development. The survey covers roughly a dozen different displays, including the latest display technologies under consideration for additional aircraft cockpits. It does not investigate sourcing of electronics for displays because the radar system study provides insights into microelectronics sourcing.

Both cathode-ray tube (CRT) and flat panel displays are examined for evidence of foreign sourcing. CRT displays remain the most widely used displays. Within this category, preference is shifting toward colored CRT displays. Flat panel displays, because of their higher cost and the technical problems in adapting them to the high-brightness cockpit environment, are expected to replace CRT displays only gradually in aircraft.

1. Cathode-ray tubes for F-18 and AV-8B cockpit displays depend on single sources in Japan for key components. Contractors estimate that between 4 and 6 years would be required to develop and qualify a domestic producer of requisite quality.

At the system level this study finds foreign sourcing of significant materials and components in cockpit CRT displays. Table II-1 summarizes the main offshore sourcing. Most such sourcing is due to the erosion of domestic capability. Most current sourcing could be replaced by development of domestic capabilities within periods ranging from 6 months to 6 years. Most significant is foreign sourcing of optical filters and filter glass from a sole source in Japan. Program managers estimate that as long as 5 to 6 years may be required to develop a replacement for this source because of the specific quality required and the production technology involved. The filters and filter glass are used in the F/A-18 head-up display (HUD), and the multipurpose display indicator is used in both the F/A-18 and the AV-8B. Reasons given for foreign sourcing of glass include the special quality

Table II-1. Sourcing of CRT Display Parts--Key Foreign and Domestic Dependence Problems

Item	Source Country (Firm)	Reason for Sourcing	Delay: Alt. Source	Reasons for Delay
F/A 18:*				
Filter Glass and Filter (HUD)	Japan (Hoya)	Only source	5-6 years	Develop skills, tooling
Molded Ferrites	Japan (Nippon)	Size of buy, complexity of part.	4-5 years	Effective machine tools, skills of workers
Glass Bulb, CRT	Japan (Sibascon) FRG (Glaswerk Wertheim)	Quality, few sources	1 year+	Training skilled workers
Optical Filter, CRT	Japan (Wakoh)	Quality not available in the U.S.	5-6 years	Tooling, training
Electronic SRUs	U.K., Florida (Smiths)	Cost	<6 months	
Casting, Chassis	Canada	Offset	>6 months	?
Comp. Factory Equipment	Japan & FRG	Cost	>6 months	?
Miscellaneous	U.K. (Smiths)	Unique components	>1 year	Tooling
Test Equipment	U.K.	Cost	>3 years	?
AV8B:**				
Enhancement Filter, CRT	FRG (Schott)	Quality not available in the U.S.	>1 year	Manufacturing process
Optical Filter, CRT	Japan (Wakoh)	Quality not available in the U.S.	5-6 years	Tooling, training
Electronic SRUs	U.K., Florida (Smiths)	Cost	<6 months	
Molded Ferrites	Japan (Nippon)	Size of buy, complexity of part	4-5 years	Effective machine tools, skills of workers
Glass Bulb, CRT	Japan (Sibascon)	Quality, few sources	1 year+	Training skilled workers
Miscellaneous	U.K. (Smiths)	Unique components	>1 year	Tooling
Test Equipment	U.K.	Cost	>3 years	?
P-7:†				
Phosphors, 30 gr.	Japan (Nichia)	Quality not available in the U.S.	1 year	Tooling, processes
Glass Funnel	FRG	Quality, few sources	>1 year	Tooling, processes
Glass Faceplates	FRG	Quality, few sources	>1 year	Tooling, processes
CD	Japan	Quality, cost	>1 year	?
<p>* There are two MDIs, one HUD, and one MPCD in single-seat F-18.</p> <p>** There are two MDRIs, one HUD, and one MPCD in single-seat AV-8B.</p> <p>† There are six display units (DUs) and five color displays (CDs) in each P-7 aircraft. During the study, no application was found for a production flat panel display on U.S. military or commercial aircraft from Japan yet.</p>				

required, the production technology underlying the quality advantage, the limited numbers and quality of alternative sources, and the special service and support from the source. Other specialized materials that would require up to a year or more for development of alternative sources include (with the estimated replacement times):

- Molded ferrite yoke (F/A-18 & AV-8B)--Japan 4-5 years
- CRT enhancement filter (F/A-18 & AV-8B)--Germany > 1 year
- Glass funnel and faceplates for CRTs (P-7)--Germany > 1 year
- Phosphors for CRTs (P-7)--Japan > 1 year
- Glass envelope (bulb) for CRTs (F/A-18 & AV-8B)--Japan > 1 year

Molded ferrite yokes are supplied by a single company in Japan and are used by Syntronic Instruments, Inc., in providing deflection coils for all the CRTs it produces. Syntronic estimates that it supplies 60 percent of all coils used for CRTs in the free world, a data point which underscores that the dependence found in defense systems broadly reflects what exists also in commercial markets. Without in-depth research it is difficult to judge whether Syntronic depends on its current source because of its technology advantage or for other reasons. However, its heavy dependence on a sole source suggests potential vulnerability, whether technological or otherwise. The long (4-5 year) period the contract: estimated for development of a comparably qualified domestic source is said to stem from the need to develop skills in the use of demanding machine tool operations required to achieve quality specifications. No U.S. source of any kind is available for enhancement filters.

Other foreign sources--of casings and electronic subassemblies--could be replaced by domestic sources within 6 months with no detrimental effects. Hence, the United States does not appear overly vulnerable in these items or associated technologies.

2. CRT component dependence involves mature technologies in which the United States has lost its edge. However, the dominant market share of foreign suppliers suggests that a substantial technology effort would be required to regain a place in fast-growing commercial and defense market applications.

Because technologies are evolving rapidly in both CRT and flat panel displays, the study considers trends in both technologies and their implications for future U.S. dependence on foreign technology. In the commercial marketplace, CRT assembly and component production are shifting to foreign locations that hold an edge in production costs and manufacturing quality in this technology.

3. In CRT technology, U.S. manufacturers struggle to maintain a viable market share from their few remaining onshore facilities.
4. In emerging flat panel technologies, industry experts consider U.S. R&D seriously underfunded compared to that of Japan and Europe.
5. Differences in national leadership and R&D commitments in high-resolution systems are unfavorable to the United States and bode ill for future U.S. technology independence in flat panels. The potential for future dependence on foreign sources in this technology appears high.

The limited state of domestic development in flat panel technologies for defense systems appears troublesome. Except for a U.S.-owned subsidiary in Canada, there is no U.S.-owned flat panel developer in North America with clearly viable manufacturing and system integration capabilities and financial base. However, several major European firms have begun to establish a manufacturing and R&D presence in the United States, but mainly through acquisition of American facilities and technology rights.

b. Aircraft Radar

The microelectronic components for three radar systems, AN/APG-66, AN/APG-68, and AN/APG-68 with Advanced Programmable Signal Processor (APSP), were examined. In these systems, 957 different microelectronic device configurations were evaluated. The study identifies five microelectronic companies that are qualified to provide a significant portion of the microelectronics parts-types or key parts for these systems. Together these firms account for approximately 35 percent of the device configurations in the radar systems. The following sections present findings based on the data collected for the various microelectronic devices used in these F-16 radars.

(i) Wafer Fabrication

- All dice used in semiconductor discrete and IC devices evaluated in the F-16 radar were fabricated at U.S. onshore facilities.

Wafer fabrication refers to the complex process of creating multiple replications of the desired semiconductor circuit design on the semiconducting material substrate (usually silicon). The output of this process is many (on the order of several hundred) individual semiconductor dice or "chips" on a single wafer. For the *nonhybrid microelectronic devices* studied, including both ICs and discrete semiconductor devices, virtually 100 percent of the dice supplied by these firms were fabricated at domestic facilities. On the basis of this evidence, fabrication of the semiconductor devices for defense applications appears to be predominantly performed onshore. However, each of these onshore

producers has offshore facilities that produce other dice used in source-control drawing (SCD) devices. Therefore, the study concludes that 100 percent domestic fabrication of dice is atypical in defense systems.

Approximately one-third of the die types used in the hybrid devices evaluated were fabricated by the onshore hybrid manufacturer visited, with the remaining two-thirds obtained from domestic suppliers (mainly distributors). Domestic suppliers indicated that roughly half of the die types that they provided were from known onshore sources. The remaining quantity (or one-third of the total die types used in the hybrids) could have come from onshore or offshore sources. The only method of verifying the mix between these sources would be to research specific "diffusion runs" (a number-tracking scheme referencing individual wafer production runs) for the actual die used for each hybrid device produced.

One special aspect of sourcing for these radar systems that may account for the high reliance on domestic fabrication is the fact that Westinghouse, the prime contractor, placed special emphasis on U.S.-sourced microelectronics during the design of the AN/APG-66. This special emphasis was due to Westinghouse's belief that a high level of domestic sourcing of electronics could be a positive selection factor in its competition with Hughes to design and develop a radar for the F-16 aircraft.

(ii) Assembly and Packaging

- Approximately 28 percent of microelectronic device types evaluated are packaged and assembled offshore.
- Approximately 67 percent of SCD device types surveyed (complying with only MIL-STD-883 or 750 screening requirements) are assembled offshore.¹¹
- For the AN/APG-68 radar parts evaluated, roughly 54 percent by quantity and 70 percent by type of JANTX semiconductor discretes are assembled and packaged offshore.
- In the AN/APG-68 radar, roughly 34 percent of microelectronic device types used (by quantity) are assembled offshore.

The study found that approximately 28 percent of the microelectronics (by types) used in the three radar configurations are packaged and assembled offshore. This percentage increased sharply for devices not required to meet the strictest Joint Army-Navy

¹¹ SCD devices must comply with specifications developed by a system or subsystem prime.

(JAN) standards (i.e., 883-screened devices). The study concludes that 67.9 percent of source-control drawing (SCD) devices are assembled offshore. More detailed information relative to these findings may be found in Tables B-II-3 through B-II-5 of Appendix B, Annex II. All 14 of the hybrid device types evaluated in this study are assembled onshore by a U.S. manufacturer.

Overall, these percentages for foreign sourcing for radar microelectronics are much lower than the pattern for assembly, packaging, and testing of commercial devices, which for some of the largest U.S. producers take place almost entirely offshore.

c. Sparrow and AMRAAM Missiles

(i) U.S. Technology

- The United States retains the technology capabilities central to designing and producing missile systems. Little offshore sourcing of *parts or components* was found in either the AMRAAM or the Sparrow *at the first and second tiers of supply*.

Minimal foreign sourcing was found in components central to the operation of the systems. At lower level vendors the study finds evidence that foreign sourcing of components and materials occurs with greater frequency, but time limits did not allow for complete analysis below the third tier of vendors. Preliminary indications are that lower tier components (especially microelectronic discrete and integrated circuit devices) are produced or packaged offshore.

(ii) Foreign Sourcing

- Chief among foreign-sourced parts and components were ceramic packages for microcircuits, and certain gallium arsenide substrates. Development of a domestic source for these items would require a year or more, according to contractor estimates.

Raw materials required for microelectronics fabrication provide some offshore sourcing difficulties for manufacturers. For example, there are no competitively priced domestic sources of high-quality merchant gallium arsenide because demand in the United States is low relative to that in Japan. As a result, the main sources of the raw material are Japanese firms such as Fujitsu. If U.S. gallium arsenide circuit makers were to lose their materials source, it would take at least 1 year to qualify a new source.

Microelectronic devices used in the missiles, radars, and displays were either found or reported to be almost totally dependent on foreign sources for the various packaging materials. Areas of dependence include: (1) ceramic packages, lids, and covers, (2) lead frames used on semiconductor discrete and IC devices, and (3) ceramic feedthroughs used on power hybrid devices. The missile study also identified dependence on foreign-sourced ceramic chip carriers. (For F-16 radar microelectronic devices studied, the dependence on foreign sources of ceramics was in excess of 99 percent.)

The primary source of ceramics (used in packages, chip carriers, and feedthroughs) is Kyocera, a Japanese manufacturer that has plants in both Japan and San Diego. Other ceramic suppliers include NTK, Naruni, and MPI. NTK and Naruni are Japanese companies, and both are located in Japan. MPI is a U.S.-owned company with all of its manufacturing performed in Singapore.

(iii) Equipment

- In contrast to parts and components, the *process equipment* required to produce many of the mechanical and electronic components in the missiles is procured extensively from offshore.

(iv) Machine tools

- One producer reported that 80 percent of its machine tools, by value, come from foreign sources. One AMRAAM subsystem producer acquires 100 percent of its machine tools from offshore.

Whether U.S. suppliers could supply key machine tools that would meet and hold tolerances required for AMRAAM production, and do so in less than the 3 years estimated by the missile prime to be the minimum required to develop a domestic source, was subject to conflicting claims that could not be resolved in the time available.

(v) Materials

- Some materials required for missile production come from a single or a limited number of foreign suppliers, such as chromium from southern Africa, and titanium from Australia. The possibility of supply disruption could be met by stockpiling or possibly, over a longer term, a technological solution such as development of an alternative material.

The amount of foreign parts and components sourcing is higher in AMRAAM than in Sparrow. This is partly due to the fact that AMRAAM has a much more complex

electronics suite than Sparrow. Decisions to procure offshore components are not mainly driven by technology, but have been based, almost exclusively, on the cost advantages of foreign-source componentry. In the cases analyzed, the United States has the capability to manufacture the items required, but is not currently price competitive. See Table II-2.

d. Heavy Combat Vehicle Engines

The heavy engine study analyzes the M1A1 Main Battle Tank engine (the AGT-1500) and the two Advanced Integrated Propulsion System (AIPS) engines being developed for heavy combat vehicles (the LV100 gas turbine and XA28 1500 hp diesel).

(i) Parts

- The study finds no foreign parts or components technologies for these engine systems that constitute a current defense system vulnerability.

The study identifies limited use of foreign technologies. Four foreign-sourced components were found in the AIPS engines and none in the AGT-1500.

(ii) Technologies

- AIPS program management has not wanted to restrict contractors in their selection of technologies during the engine development phase. Contracts stipulate that the contractor is free to use any source for technologies or parts. However, domestic sources must be used during the production phase.

Such requirements extend prospects of U.S.-dominated sourcing into the coming generation of heavy vehicles. Implicit in this approach is the assumption that the volume of vehicle procurements will justify investments required for dedicated production facilities in the United States. With budget cuts and prospective decreases in conventional forces in Europe, this assumption may eventually require revision.¹²

(iii) Equipment

- Extensive use of foreign machine tools is evident in both the AGT-1500 and planned AIPS engine production facilities, and foreign sourcing is increasing.

¹² In recent days Defense Secretary Cheney has reportedly alluded to a possible reduction of M1A1 production from a current annual rate of 600 to a reduced rate of 200 per year.

Table II-2. Summary of Findings: Missiles

Part/ Component	Source	Reason for Sourcing	Delay to Develop Alternative	Reason for Delay
AMRAAM				
Guidance and Control				
Precision machine tools	Japan	High tolerances	Est. 3-5 yrs	Time required to develop necessary tolerances.
Radome--magnesite	Mexico	Only source	Indefinite	Develop and qualify alternative material.
FETS and capacitors	Japan (Fujitsu)	Cost	N/A*	Use qualified alternative domestic sources.
Ceramic chip carriers	Japan (Kyocera)	No domestic supplier.	Indefinite	Qualify alternative domestic source.
Hybrid circuit components	Asia, Europe	Cost	~ 6 mos	Use qualified alternative domestic sources.
Gallium arsenide	Japan (Fujitsu); FRG	No domestic supplier.	> 1 yr	Develop new qualified source.
Actuator motor	U.K. (Lucas)	Cost	None**	Use other qualified domestic sources.
Warhead				
Warhead shell material	U.S. sole source	Sched. delays	1 yr	Qualify other domestic vendors.
Painted wiring board	U.S. (Asher)	Single source	>6 mos	Qualify other domestic vendors.
Titanium	Australia	No economic domestic source.		Qualify currently uneconomic materials.
Chromium	So. Africa	No domestic source.	Indefinite	Develop alternative materials.
Rocket Motor				
Propellant chem. (IPDI)	FRG (Huls)	No U.S. source (EPA).	Waive EPA	Qualify U.S. processes.
Propellant chem. (HPTB)	U.S. (Fr. owned)	Sole source	Indefinite	Develop domestic-owned source.
Flow-form machine	FRG (Lifeld)	Cost	< 1 yr U.S. supplier	Vendor backlog.
SPARROW				
Guidance and Control				
Precision machine tools	Japan	High tolerances	Est. 3-5 yrs	Time required to develop necessary tolerances.
Silver	TBD†	TBD	< 6 mos††	Qualify substitute battery material.
Warhead				
Printed wiring board	U.S. (Asher)	Single source	> 6 mos	Qualify other domestic vendors.
Rocket Motor				
Propellant chem.	TBD			Qualify U.S. processes.
Flow-form machine	FRG (Lifeld)	Cost	< 1 yr U.S. supplier	Develop domestic-owned source.
* Not available at time of publication. ** Motor has two U.S. sources which presently compete for actuator motor procurements. † To be determined. †† Current battery being replaced by new type using improved technology, with no foreign sourcing.				

This is particularly true in grinding, machining, and turning (lathes and milling) machines. Reasons cited for foreign sourcing include lower cost; shorter delivery schedules; better responsiveness to procurement specifications service requirements; and better operational capabilities, usually expressed as abilities to meet and hold precise tolerances.

Table II-3 summarizes the main findings of foreign sourcing in the two programs, the reasons for the choice of foreign sourcing, the estimated delay required to establish and qualify domestic source alternatives, and the reasons for the time required. For complete explanations, see Appendix B, Annex IV.

Table II-3. Summary of Findings From Studies--Tank Engines

Part/ Component	Assembly	Source	Reason	Delay for Alternative	Reasons for Delays
AGT-1500	Textron Lycoming				
Machine Tools	Milling, turning, grinding	FRG, France, Italy, JA, UK, Switz	Cost, del. qty, svc. availability	Indefinite	Development of technology base
LV100	GE--Textron				
Recuperator	Engine	FRG	Qty/rel/\$	2+ yrs	Development and qual. testing
Low-Pres.Turb.	Engine	FRG	Schedule/\$	2+ yrs	Development
Air Filter	Engine	FRG	Qty/rel/\$	2+ yrs	Development and qual. testing
Machine Tools	Same as AGT-1500	FRG, JA, etc.	Cost, etc.	Indefinite	Development of technology base
XAV28	Cummins Eng. Co.				
Injector solenoid	Engine	JA	Cost	1+ yr	Install prod. tooling
Head Bolts	Engine	FRG	Cost	No delay	N/A
Machine Tools	Same as AGT-1500	FRG, JA, etc.	Cost, etc.	Indefinite	Development of technology base

(iv) Equipment Outlook

- Increasing reliance on foreign-sourced production equipment is reason for concern that continued erosion of U.S. machine tool and other equipment industries could place U.S. defense manufacturers in a vulnerable position.

Risks could arise in a near-term (3-5 year) surge situation, or in the longer term from complete U.S. loss of some production technologies.

Machine tools are obtained from a variety of European and Asian sources, but increased dominance by a single country could increase the uncertainty of the U.S. position over the coming decade. While not a problem when production requirements can be met from existing plant, foreign sourcing can become hazardous if surge requirements develop, or if emerging defense systems depend on ever more technologically advanced equipment, or if technology advances so rapidly that new generations of product and equipment rapidly succeed each other, as in the microelectronics industry.

(v) High-End Machine Tools

- The study finds increasing use of foreign-made machine tools, particularly the more costly, technology-intensive numerically controlled grinding, milling, and multiaxis machining centers.

Textron Lycoming, manufacturer of the AGT-1500 and codeveloper of the LV100 turbine engines, in an analysis of machine tool purchases from 1985 to 1989, shows that:

- Almost 45 percent of one prime's \$26 million modernization program went for the purchase of foreign-made machine tools.
- Foreign sources accounted for 69 percent of high-end tools (over \$200,000 each) acquired during modernization.
- The average cost of machine tools is \$179,000 for imported tools versus \$41,000 for domestic tools--reflecting the greater technology sophistication embodied in the foreign-made tools.

Engine system manufacturing managers stated that:

- Over time a growing percentage of machine tools that prime buys to replace older equipment will come from offshore
- Parts of many U.S.-labeled machine tools are manufactured offshore but assembled in the United States.¹³

Foreign machine tool dominance is not restricted to the more costly, high-precision, numerically controlled (NC) machines. Foreign manufacturers, primarily Japanese, are making a strong bid to take over the low end of the U.S. machine tool market as well.

¹³ As a variant of this problem, the missile study found, from an industrial preparedness survey by one prime contractor, that one of the largest U.S. makers of test equipment determined that much of its equipment production is dependent on foreign semiconductors, many of which were chosen as the only component available for the specific technology required.

The ongoing erosion of domestic machine tool industry has continued into the 1980s as illustrated in Table II-4 by data provided by the National Machine Tool Builders Association (NMTBA).

Table II-4. Domestic Machine Tool Companies

Year	SIC 3521-- Metal Cutting	SIC 3542-- Metal Forming
1982	293	162
1987	245	126
% Change	-16%	-22%

The success of foreign machine tool manufacturers in gaining U.S. market share has been given as one factor in the decline of the U.S. industry. As one evidence of this success, the NMTBA provided the data in Table II-5 on total tool sales and total foreign tool sales in the United States to 1989.

Table II-5. U.S. Machine Tool Purchases

Year	Total Purchases	Foreign Tool Purchases	% Foreign
1985	\$3.970B	\$1.689B	43%
1986	\$4.380B	\$2.217B	51%
1987	\$3.965B	\$1.969B	50%
1988	\$3.924B	\$2.032B	52%

Some U.S. producers have abandoned some or all of their tool lines because of loss of sales, leaving the market for those tools open to foreign suppliers. This is particularly true in the case of numerically controlled, multiaxis machine tools and machining centers.

Overall the machine tool industry has seen a doubling of market share by foreign imports from 26 percent in 1982 to a leveling out at around 51-52 percent in 1986-88. It has also seen a rise in foreign investment and ownership of domestic producers. Both trends were encouraged by domestic producer decisions, in response to intensified foreign competition, to enter into partnerships with foreign firms and to buy parts and components from overseas in order to cut costs.

B. IMPACT OF DEFENSE LAWS, POLICIES, PRACTICES, AND PROGRAMS

1. Overall Policy Guidance: Domestic Base and International Cooperation

Two major lines of DoD policy establish guidance that affect basic sourcing decisions.

a. Acquisition

- One line originating with the Under Secretary of Defense for Acquisition [USD(A)] establishes basic acquisition policies and procedures. This line involves multiple acquisition objectives that influence sourcing decisions.

The broad objectives of this line of policy include cost reduction, competition, defense industrial supply base, industrial preparedness planning, and administration of mandated policies such as export controls, Buy American, and small-business set-asides. Within OUSD(A), responsibilities and guidance for these different objectives often conflict. For example, cost reduction objectives that encourage offshore procurement may conflict with measures to protect and support the defense industrial base and Buy-American provisions.

b. Cooperation

- The other line, originating with the Under Secretary of Defense for Policy, emphasizes defense cooperation and an alliance-wide industrial base concept. It relates primarily to NATO but also to relations with other allies.

Guidance from responsible offices reporting to these two Under Secretaries extends down through the chain of command to the system program officer and beyond. When conflicts arise, in most cases no system or procedure exists to resolve them.

There is one notable exception to the general lack of a clear system for resolving guidance conflicts: when choices take place within the framework of *International Security Agreement MOUs*, waivers from Buy-American provisions are encouraged by directive in order to foster sourcing from alliance countries. In other cases, the system program office has to decide which chain of acquisition guidance should have precedence, and will convey its decision to contractors through contract terms or by other means. It is likely to choose the guidance that best suits the priorities of the program. For program managers, specifications, cost, and delivery dates are often the most powerful drivers, followed by quality assurance.

c. Conflicting Policy Developments

- IDA system studies find examples where new policy developments *discourage* foreign sourcing for defense industrial and technology base reasons. At the same time other procurement cost reduction policies have *encouraged* low-cost (often foreign) sourcing.

Over the past several years, the USD(A) sponsored several studies that heightened attention to the eroding defense industrial and technology base and proposed strengthening both by implementing measures that *reduce or prevent foreign sourcing*.

Over roughly the same period, beginning with Congressional passage of the Competition in Contracting Act in 1985, DoD also began to implement procedures aimed at increasing the scope of competition in the acquisition process, including increased requirements for second sources. Emphasis on competition has been accompanied by intensified government assertions regarding rights to technical data from developers. DoD often uses this data to invite bids from second or alternate sources. Pressures for cost containment encouraged efforts to find low-cost sources, including use of offshore sources.

Current defense budget cuts and prospects of further cuts may force a reevaluation of acquisition objectives, eventually resulting in increased foreign sourcing. One example is a recent DoD policy statement emphasizing international cooperation as a major means to reduce defense costs.¹⁴

Among the major defense laws, regulations, and policies that form the framework of defense acquisition and sourcing practices are:

- Defense System Acquisition Directive 5000.1 and instructions for major defense system acquisitions (encourages maximum acquisition cooperation with allies, but with due consideration for surge/mobilization requirements)
- Competition in Production Act, Federal Acquisition Regulations (FAR) Part 6, provides for full and open competition, program competition advocates, and authority to exclude foreign sources and conduct non-competitive procurement for national security reasons, subject to compliance with conditions justifying such exclusions and direct procurements.
- Military Standards, testing and procedures require special performance and qualities exceeding commercial standards, special qualification of production

¹⁴ *Defense News*, 16 October 1989, p. 24. See also *Report of Defense Science Board on Defense Industrial Cooperation with Pacific Rim Nations*, October 1989.

processes, and special testing, audit and inspection procedures. Many of these disqualify foreign suppliers and dissuade domestic producers from competing.

- **Industrial Preparedness Planning** and related policies require identification of foreign dependence and of foreign suppliers of defense materiel to U.S. and Canadian suppliers. In practice, no provision is made for staffing to monitor or procedures to assure compliance.
- **Export Controls**: The International Traffic in Arms Regulations (ITAR) and Export Administration Regulations (EAR) control release of critical technologies to potential adversaries.
- **Other Provisions**: Buy-American provisions and small-business set-asides both preempt foreign sourcing in cases where they are invoked.

2. Defense Acquisition Requirements

- Many acquisition requirements have adverse effects on U.S. sourcing. This study identifies many examples of contractor complaints regarding adverse effects on domestic sourcing caused by various acquisition requirements.

Some acquisition policies clearly reduce foreign sourcing--e.g., those intended to assure rigorous quality control and supply security with a domestic source. Some policies have effects that differ according to the circumstances. For example, requirements that SPOs assure a second supply source may reduce foreign sourcing if the single source is foreign, but increase it if the current sole source is domestic.

Acquisition policies currently:

1. Limit use of foreign parts and components at the prime and second tiers, but have progressively less effect at lower tiers where tracking and accountability are greatly reduced.
2. At the part and component levels, lose their ability to limit foreign sourcing where U.S. product or manufacturing technology is severely eroded.
3. In materials, have little effect in reducing foreign sourcing of those that are available predominantly or exclusively from foreign sources.
4. Have little or no effect at the equipment and process level because this "sourcing" falls beyond the scope of present defense acquisition regulations.

Although some policies and programs clearly encourage use of the best technology regardless of its origin, many other prevailing policies and procedures may cause actual program sourcing decisions to differ from a "best technology" choice. Only one of the programs studied explicitly encourages evaluation of relevant foreign technologies.

Additional concerns were raised by contractors and suppliers interviewed during the course of the study. A majority of complaints cited practices considered unnecessarily burdensome, which raise the cost of doing business with DoD in contrast to prevailing commercial marketing costs. These problems may cumulatively contribute to the steady decline in defense contractors even during a period of rising defense budgets. One source claimed that from 1982 through 1987, as many as 80,000-100,000 firms may have withdrawn from the U.S. defense market.¹⁵ While many would dispute a decrease of this magnitude, a marked decline is generally accepted. There are many possible explanations for such a decrease, but our research contacted several firms which no longer find it profitable or worth the risks to do business with DoD, and which have decided to withdraw from the defense business.¹⁶ (These interviews took place before reports of administration plans for major defense budget cuts appeared in the press.)

a. Military Standards and Specifications

- Service specification differences remain widespread, and other standard conflicts reportedly raise contractor costs, cut profits.

Economic production of key components is complicated by unique specifications for each service. Manufacturers absorb higher costs training people to implement and inspect different service requirements. Meeting each service's specifications is a problem in joint-service programs. Dual specifications are likely to generate additional conflicts once the system is approved for full-scale production. Defense suppliers must also invest their own time and money resolving other types of specification conflicts found in system studies.

b. Testing and Screening Procedures

- Excessive or redundant defense testing and screening requirements raise costs and place U.S. firms at a competitive disadvantage with foreign suppliers.

For example, requirements for component testing sometimes have built-in redundancy, which suppliers often consider unnecessary (see Appendix B, Annexes II, III). For example, suppliers are required to perform a 100 percent testing of semiconductors out the

¹⁵ *Deterrence in Decay: The Future of the U.S. Defense Industrial Base*, Washington, D.C.: Center for Strategic and International Studies, 1989.

¹⁶ This finding is substantiated by Richard W. Stevenson, "Foreign Role Rises in Military Goods," *New York Times*, 23 October 1989, p. 1.

door to the prime, and the prime is required to perform 100 percent testing upon receipt. Additionally, many vendors insist that products that meet commercial standards are as good if not better than those built to military specifications. Thus program managers or primes often have incentives to expand the use of commercial components produced offshore in order to reduce program costs.

c. Certification/Qualification Costs

(i) Qualified Manufacturers Lists (QMLs) and Qualified Products Lists (QPLs)

- "Qualified Manufacturers Lists" will reduce costs; however, certification of offshore manufacturers as QMLs would eliminate incentives to use domestically produced parts and increase use of offshore microelectronics.

Current policy requires certification of a "Qualified Products List" (QPL) for each MILSPEC device produced. A new quality assurance concept proposes to authorize a "Qualified Manufacturers List" (QML), certifying a company's production line and processes for production of an approved range of MILSPEC parts.

Manufacturers strongly support the new concept as a way to reduce device cost and streamline the certification process without jeopardizing product quality. They agree, however, that if offshore facilities are made eligible for the QML certification process, onshore MILSPEC facilities will be forced out of business.

(ii) Parts Selection Order of Precedence

- The microelectronic parts selection order of precedence is a significant factor in reducing the current DoD reliance on foreign-sourced microelectronic devices.

Microelectronics manufacturers maintain that the DoD microelectronics parts selection order of precedence generally cited in contracts (MIL-STD-454) influences system primes to acquire devices that are fabricated and assembled domestically by U.S. sources. If DoD were to eliminate the current order of precedence, the manufacturers believe that primes would have little incentive to acquire domestically produced microelectronic devices and there would be inadequate business basis to justify maintaining U.S.-based MILSPEC production lines. As a result, if DoD wants MILSPEC parts produced onshore, this requirement needs to be specified in contracts with primes.

d. Audit and Quality Assurance Procedures

Severe performance requirements for many DoD systems require tight quality control. However, manufacturers interviewed for the missile study, with one exception, judged the audit process to be out of control.

Because the AMRAAM program has been a source of controversy, there has been a need to step up the auditing and quality control procedures. The Defense Contract Audit Agency (DCAA) is responsible for auditing administrative and financial aspects of the contract to see that competitive procedures are complied with and that proper contracting methods are used. The Defense Contract Administration Services (DCAS) is responsible for certifying that products meet technical specifications in the contract. Its personnel are the onsite DoD technical representatives. Other audits are conducted by the program office, and the services. The Hughes AMRAAM production facility in Tucson underwent four complete audits between April and September 1989. Hughes personnel expressed concern for such extensive auditing procedures, particularly for how they affect smaller suppliers which have less flexible production schedules and tighter manpower constraints.

The orientation of DCAS personnel is also a concern of contractors. They maintain that when DCAS personnel work *with* a manufacturer to improve quality, both DoD and the manufacturer benefit, but if DCAS representatives adopt an "us versus them" attitude, it can work to the disadvantage of both the manufacturer and DoD.

e. Cost Accounting Rules

- Current cost accounting practices raise parts cost to DoD, making U.S. parts less competitive than parts produced offshore or not otherwise subjected to these practices.

Federal Acquisition Regulations (FAR 15.804) require separate cost accounting on Standard Form 1411 for products (including microelectronics) for negotiated contracts that are expected to exceed \$100,000. In addition, many defense primes require the 1411s for negotiated prices well below that sum. Separate cost accounting for a specific microelectronic product often requires a manufacturer to separate military and commercial production. The resulting lower volumes for defense orders generally cause production lines to run below capacity and often discontinuously, creating higher overhead costs per unit and longer delivery times. Manufacturers believe these regulations help make onshore-produced microelectronics less competitive than offshore-sourced devices.

The Defense Acquisition Regulation Council (DARC) is studying possible expansion of the range of exemptions for cost and price accounting data and is considering options to permit price quotations to reflect sale prices to the general public. A final decision is still 6 to 12 months away.

f. Second Sourcing and Data Rights

(i) Rights assertion

- Some firms cited the government's vigor in asserting its rights to technology developed even partly with public funds as a direct cause of numbers of firms' leaving the defense industry.

When new technologies are developed with governments funds, the rights to the data are claimed by the government, and are often used to develop second sources. If contractor R&D funds are used (in addition to government funds), contractors maintain that the firm should own the data rights. One SPO detailed the case of a vendor who developed a product specifically for a DoD application using corporate funds. DoD claimed the data rights and gave the design package to a competitor for manufacturing competition. The originating vendor decided it was not worth the trouble to continue to market products to DoD and left the business.

(ii) Impact

- DoD transfer of technology data to prospective second sources in order to attract bids not only means that developers lose proprietary advantage, but also assures that the original firm faces loss of profitability from the technology it developed.

While this practice may cut procurement costs in the short run if a domestic second source is acquired, it may raise them over the longer term, especially in light of the downward trend in the number of firms said to remain in the defense industry.

Prime contractors invest time, effort, and money complying with requirements to qualify second sources. Qualifying a second source is problematic (1) if the technology is complex and the size and timing of production lots are uncertain (as with AMRAAM) or (2) if it takes place late in the life of an older system likely to be replaced in the near future (Sparrow). Suppliers are acutely aware of how long it will take to recover invested capital in programs such as missiles, particularly when a production lot is split between two competing firms. If a second source is pursued in products for which the defense market

cannot profitably support a second source, suppliers will suffer cost increases and inadequate returns until one withdraws.

g. Export Controls

- Trade restrictions have the potential to inhibit development and use of new technologies.

The International Traffic in Arms Regulations (ITAR) and Export Administration Regulations (EAR) control the export of critical products and technologies to potential adversaries. In technology areas such as microelectronics, commercial producers are developing and marketing technology products that will not find wide DoD systems application for years after they are available in the commercial market. U.S. manufacturers argue that export control restrictions to foreign markets cause developers to lose revenues critical to sustaining R&D and learning curve momentum, as well as losing economies-of-scale opportunities and losing market shares to foreign competitors.

3. Defense Programs Influencing Technology Sourcing

This study looks beyond systems in current production to determine whether enhancement and upgrade programs influence foreign sourcing of technology incorporated into systems beyond initial production. In particular, the study considers:

- Productivity enhancements. For example, the AMRAAM program has developed an "AMRAAM Productivity Enhancement Program," or APREP, through which it solicits recommendations of ways *to reduce costs* of production from contractors .
- Preplanned program improvements (P³I). In recognition of long defense system gestation periods (more than 10 years for AMRAAM), program offices can take advantage of technology insertion programs such as P³I *to reduce costs and enhance performance.*
- System modernizations, enhancements, and upgrades. Pairs of related systems were selected to look for changes from one "generation" to the next (e.g., Sparrow to AMRAAM) in technology sourcing. Typically the older system and sometimes the more recent one will undergo block upgrades or enhancements. In land-based propulsion, TACOM has undertaken a far-reaching Advanced Integrated Propulsion System program to modernize engines for tanks and other heavy vehicles.

- (1) No Clear Pattern: The study finds no clear pattern that enhancement and upgrade programs either reduce or increase foreign technology sourcing because program offices still have a wide variety of sourcing options available within procurement regulations.
- (2) A Best-Case Strategy: In a "best case" example, a heavy vehicle engine development program aims at drawing on the best technologies from all sources while requiring production in the United States.
 - A major benefit of the AIPS program is that with AIPS funding a U.S. firm was able to develop and build an armored diesel engine that incorporates state-of-the-art technology developed in the United States and abroad, but heretofore incorporated only in European-designed armored vehicle diesel engines.
 - In the same program, the program office invited designs using either domestic or foreign technologies, while requiring that all production of successful designs take place in the United States.

Thus the program office has used available programs creatively to (1) accomplish a major upgrade of U.S. technology; (2) access the best technology; (3) encourage design and development competition in both domestic and foreign sources; and (4) assure domestic sources by requiring production in the United States. However, its domestic sourcing objective may be jeopardized to some degree if defense budget cuts reduce engine demand below levels necessary to justify investments in domestic production capacity.

4. Offsets

- Several industry sources cited offset arrangements as being responsible for some offshore sourcing.

Several independent studies have identified offsets as a rapidly growing factor in procurement arrangements between U.S. and foreign firms.¹⁷ Rapid economic development and transfer of technology has permitted more countries to aspire to strengthen and diversify their defense industries by demanding offset purchases of their components or systems as a condition for their purchase of U.S. defense equipment. Declining defense budgets have also created a buyers' market, giving more leverage to offset demands. Responding to this growing pressure, DoD recently shifted from a hands-off policy and intervened to limit Korean offset demands in its fighter development program.¹⁸

¹⁷ *Offsets in Military Exports*, Office of Management and Budget, December 1988.

¹⁸ *Defense News*, 18 September 1989, p. 3.

C. ECONOMIC AND FINANCIAL FACTORS

1. R&D Funding

(a) Direct Access

- DoD mechanisms for funding independent research and development (IR&D) rely primarily on allocations to prime contractors. These funds do not reach subtier component and equipment manufacturers that supply critical specialized technologies.

Several firms cited lack of *direct* access to R&D funds for both display and microelectronics technologies as an obstacle to improving the U.S. position in these technologies. This concern has also particularly affected subtier suppliers in both microelectronics and display systems, and in precision and other advanced machine and equipment industries supplying tank engine and missile programs. These suppliers argue that IR&D allocation policies hamper U.S. producer ability to develop competitive technologies in these fields. When DoD injects R&D funding at the prime level, little money is said to reach subcontractors, which are often the most important innovators in technologically competitive sectors. (Primes are often mainly assemblers.)

(b) Limited Funds and Lack of Vision

- DoD funding does not provide adequate R&D resources to component or equipment suppliers.

Many see both DoD and U.S. industry as lacking the vision and leadership in pushing new technologies that they see being exerted in leading competitor nations in Europe and Asia. This failing was particularly noted among manufacturers of display systems in which both Europe and Japan have major government-industry cooperative programs to develop the technology.

2. Tax Laws Affecting Machinery and Equipment; State Taxation of Inventories

- Machine Tools: The protective effect of U.S. tariffs on machine tool imports is partly offset by state taxes on unsold inventory.

U.S. tariff law provides U.S. machine tool manufacturers a modest advantage in the domestic market. When imports exceed 35 percent of U.S. machine tool purchases in any given year, tariffs of 4.4 to 4.8 percent are applied to imports of foreign machine tools,

with slightly higher tariffs on gear-making equipment. However, a number of states tax producer inventories of unsold capital equipment. Thus U.S. firms carrying a large inventory to provide quick delivery upon receipt of an order are penalized by having to pay inventory taxes, on top of the normal costs of carrying unsold inventory. This puts U.S. firms at a competitive disadvantage in an industry where quick delivery time is critical to success and foreign competitors do not face similar constraints. Thus foreign competitors generally offer much quicker delivery on a wider range of machine tools than do U.S. producers.

III. CONCLUSIONS AND RECOMMENDATIONS

A. EXTENT AND SIGNIFICANCE OF FOREIGN TECHNOLOGY SOURCING

The following general conclusions and recommendations from four system studies emphasize both *research initiatives* and *acquisition policy actions* which can be taken to reduce foreign technology sourcing judged to entail unacceptable risks for defense systems.

1. General Conclusions

1. Concentrations. The most significant concentrations of foreign technology sourcing were found in microelectronics, certain types of production equipment, advanced and specialty materials, and high resolution displays.

2. Trends. Foreign sourcing of technology exhibits an increasing trend in microelectronics, machine tools, lithography equipment, and high resolution systems. There is no evidence that this trend will reverse in the absence of some government intervention.

IDA study findings indicate that in a number of advanced technology areas, U.S. manufacturers are well behind or are falling behind foreign counterparts. Particularly, the amount of foreign technology used in *production* of the defense systems we evaluated appears to be growing steadily.

The development of enhanced and new defense systems will be increasingly dependent on rapidly evolving technologies, with microelectronics among the frontrunners. For this reason, *dependence on foreign sources for these basic defense technologies and related production technologies should be viewed less in terms of risk of potential foreign denial or disruption, and more in terms of risk to U.S. ability to remain in the lead in defense system development.*

To slow or reverse foreign technology sourcing, a concerted effort would be needed (1) to decide which areas of foreign technology dependence entail the most serious risks for defense system development in the future, (2) to review present defense acquisition practices which may increase foreign dependence, (3) to consider broad

economic policy changes necessary to facilitate economic survival of important defense production technologies in the United States, and (4) to focus research efforts on specific technologies in which a surviving domestic capability is essential for the development of future defense systems. While changes in acquisition and microeconomic policies may be generally desirable in any event, decisions to devote more research resources to reversing deterioration in U.S. technology leadership would require a combination of dependence risk assessment and cost-benefit research.

3. Current Technology Risks. This study finds no imminent vulnerability from foreign denial or delay of technology in the defense systems studied. However, the erosion, verging on demise, of U.S. capabilities in *semiconductor fabrication and machine tool technologies* is cause for serious concern because both are key to development of future defense systems. If DoD considers the prospect of foreign supply dominance or monopoly too great a risk in these two critical technologies, then both R&D and acquisition policy actions are required. The lagging U.S. effort in flat panel displays raises a similar concern.

Because of very short semiconductor generations, preferential supply of the latest generation of production equipment by a foreign supplier to a home firm can cause a potentially significant delay of supply to American users with adverse effects on defense technology research and even on the viability of U.S. user firms. The same general problem also arises in the machine tool area.

4. Mature Technologies. Study analysis shows heavy dependence on a few *highly concentrated foreign sources* (Japan and Germany) in four mature technologies. These were once well established in the United States by merchant industries but were lost as offshore producers gained cost and volume advantages. They include semiconductor materials such as ceramic packaging and semiconductor grade silicon, as well as specialty ferrite, glass tubes, and optical materials required for CRT displays. However, only in extreme circumstances is there any likelihood that the United States would face interruption or delay of supplies.

5. Responses to Risks. In these mature technologies, foreign sourcing appears reversible. Programs to develop domestic sources might prove commercially feasible in cases where sufficient (expanding) defense demand exists or arises, but procurement costs would at best be greater than foreign sourcing and would at worst be prohibitive. Industrial base or procurement programs are more appropriate than research programs for addressing any need for domestic sourcing that is determined in the mature technologies area.

2. General Recommendations

1. Research Priorities. DARPA should give priority consideration to four of the technology areas identified by this study: (1) microelectronics production equipment, (2) machine and other precision production equipment, (3) high-resolution display technologies (CRT and flat panel), and (4) advanced materials (gallium arsenide, ceramic packaging, and semiconductor grade silicon). These priorities should apply not only in developing DARPA's strategy for advanced research, but also in coordinating its research priorities with acquisition policies.

2. Survey and Monitor. Because of the unique importance of microelectronics and machine tools in future weapons development, DoD should undertake a *broader survey* of offshore sourcing of defense production, assembly, and testing equipment than was possible in this study. Its aim should be to identify emerging foreign equipment sourcing trends and to help focus research on equipment technology migration offshore that poses greatest potential risks for U.S. leadership in weapons system development.

3. Conclusions and Recommendations in Specified Main Areas of Dependence

Conclusions and recommendations in the four main areas of dependence identified by the four system studies are the following.

a. Microelectronic Devices and Semiconductor Materials

(i) Parts Sourcing

Conclusion. Trends in microelectronics parts used in radar are away from MILSPEC devices, fabricated and assembled domestically, toward MIL-STD-883-screened devices that are predominantly assembled offshore. The study did not find serious imminent risks of denial or disruption in present sourcing patterns, but the degree of foreign dependence could increase markedly if current sourcing policies were liberalized. The greater risk arises from prospective loss of lead times in possession of leading-edge technologies required for leadership in defense system development.

Recommendations

- Since one of the greatest immediate challenges to continued onshore device production arises from pending acquisition policy issues, these more-than-research issues deserve priority attention in the short term.
- Continued DARPA research support in semiconductor production improvement is strongly indicated.

(ii) Packaging and Assembly

Conclusions. The potential for reducing exceptionally high U.S. dependence on foreign ceramic packaging is most attractive for advanced, high-definition devices. DoD could also benefit from cheaper packaging technologies that meet the high quality and reliability needs of DoD to reduce the cost of domestic semiconductor devices.

Recommendation. DARPA should consider research in advanced packaging materials, processes, and assembly technologies for DoD's most advanced quality and reliability microelectronics device requirements. DoD should encourage procurement authorities to consider efforts to drive down unit ceramic packaging costs for defense system devices to help make U.S. products more competitive with offshore products.

(iii) Advanced Semiconductor Materials

Conclusion. Analysis of radar and missile systems reveals virtually complete dependence on foreign sources for ceramic packaging and high dependence on a few foreign sources for semiconductor silicon and gallium arsenide materials. Defense systems could face risks in the event of *short-term* supply disruptions (e.g., natural disasters) or excessive commercial demand leading to supply rationing.

Recommendation. Stockpiling is not technically feasible for key advanced semiconductor materials beyond the short term. Remedial actions might include DARPA research emphasis on high-quality semiconductor material processing and research initiatives in packaging and assembly technologies. However, justification for making this a research priority should depend on prior assessments by radar, missile, and other system program managers of the potential costs and risks of foreign supply disruptions.

(iv) Semiconductor Equipment

Conclusion. The weak competitive position of the U.S. lithography industry raises concerns about the future ability of the U.S. semiconductor industry to obtain the best production equipment early enough (1) to keep pace in international competition and (2) to meet DoD requirements for remaining at the leading edge in defense electronic systems development.

A demonstrable risk arises with each new generation of equipment, as an inevitable short-supply situation arises in meeting producer demands for the latest equipment. Foreign suppliers naturally favor their best and largest customers, which are most often their own home firms. With new equipment generation life now diminishing to 2 or

3 years, a relatively short lag behind competitors in getting crucial equipment could cost U.S. producers their best chance for competitiveness and profitability in the highly volatile semiconductor business, and could increase DoD risk of losing defense electronic technology leadership.

In lithography Japanese suppliers have gained dominance in global and U.S. markets. Had Perkin-Elmer sold its lithography business to a foreign buyer, the United States would have faced, but for one remaining U.S. supplier, total dependence on foreign sources for this equipment and a growing concentration of sourcing in a single country, both posing a substantial risk to the viability of U.S. semiconductor technology.

Recommendation. DARPA research support for lithography appears essential to bolstering the survival prospects of this technology in the United States. DARPA should supplement SEMATECH activities in this field by funding a program in advanced microelectronic lithography to support alternative domestic developments of lithographic processes needed for defense applications.¹⁹

b. Machine Tool Sourcing

Conclusion. IDA missile and engine system studies, which provided the greatest amount of equipment sourcing data, found high and growing dependence on foreign machine tools and numerically controlled production equipment, ranging from 50 to 100 percent at important prime and component manufacturers. Foreign supply domination could pose major problems for future U.S. defense production flexibility. Supply delay or disruption could arise under a number of plausible circumstances, commercial as well as political-military, and justifies priority DoD attention.

Lack of economies of scale, related to large and faster growing foreign markets, are fundamental problems that need as much DoD attention as technology enhancements.

Recommendations

- Program Manufacturing Technology. DARPA should undertake efforts to foster manufacturing process research for existing procurement programs under the current DARPA Initiative for Concurrent Engineering (DICE) program. This would provide an incentive for current program manufacturers to upgrade current product and manufacturing processes to reduce

¹⁹ On the basis of other studies reviewed during our research, it appears that these programs should include extensions of current optical technologies, direct-write electron beam, compact soft X-ray techniques, and the mask technologies required for these lithography tools, at feature sizes of 0.5 μ and below.

manufacturing time, production costs, and yields, and to improve overall product quality and reliability. To succeed, DARPA would have to negotiate an incentive program with the procuring agency that would permit contractors to accrue some of the benefits gained through such a program, even though the R&D might be sponsored by DARPA; otherwise, improvements that reduce DoD program production cost would also reduce the profits of the producing company.

- General Manufacturing Technology. DARPA, in coordination and cooperation with DoD and service program and procurement authorities, should fund R&D programs to develop superior manufacturing processes around U.S.-made machine tools. When U.S. machine tools are found to be lagging behind the pacing technologies, DARPA should fund R&D directly with machine tool manufacturers. DoD procurement authorities should encourage greater efforts by system suppliers to cooperate with and invest in equipment improvements by U.S. machine tool and process equipment suppliers.
- FAR and DFAR Amendment. USD(A) should initiate changes in the FAR and DFAR guidance governing allowable IR&D expenditures to encourage the spending of IR&D funds on development of U.S. manufacturing processes, machine tools, and other manufacturing and process equipment.
- IR&D. USD(A) should encourage the spending of IR&D funds on development of manufacturing processes and machine tools. Consideration should be given to requiring that technologies developed by this route can only be licensed initially to U.S. firms, preferably for production within the United States.

c. Materials Sourcing

The four system studies identify a number of processed materials based on well-established technologies in which U.S. production and technology capabilities have eroded or disappeared, leaving defense systems heavily or completely dependent on a few foreign sources. In some cases, DoD procurements are of such a low volume that economies of scale now heavily favor dominant foreign producers. In some of these cases, the prospects for technology solutions are so limited, or other factors are so limiting, that efforts to develop domestic sources would make no economic sense. Such is the case for certain missile propellant chemicals and engine head bolts found by current studies.

Conclusion. In a few cases, foreign-sourced specialty materials involve substantial dual-use markets. Some of these might warrant procurement efforts aimed at achieving production technology and cost breakthroughs that would permit the restoration of a

competitively viable U.S. defense or dual-use production capability. Such might be the case for some processed materials used in display systems. Such efforts are more appropriately the responsibility of DoD procurement authorities than of DARPA.

As examples, certain critical display technologies and components--specifically, optical filters and molded ferrite deflection coils (used in commercial and defense CRT tubes)--are only available from a single firm or small number of firms in Japan and Germany. The development of onshore sources could eliminate some defense concerns. If the combined volume of domestic defense and commercial demand for these items were not large enough to assure commercial market viability, the issue would be whether supply risks and future requirements warrant development of an arsenal capability.

d. Displays and High-Resolution Systems

Conclusions. Flat panel technology will replace CRT displays gradually but not completely in military aircraft. In CRT displays, U.S. manufacturers are struggling to maintain a viable share of the world market from their few remaining onshore facilities.

In emerging flat panel liquid crystal display technologies, the U.S. commercial manufacturing base is limited. Advanced manufacturing capability for flat panel displays resides almost exclusively offshore. Moreover, U.S. R&D in flat panel displays is seriously underfunded compared with that of Japan and Europe. Especially in Japan and France, companies are developing large flat panel displays for both military and commercial uses.

Recommendations

- CRT Technology. OUSD(A) should assure IR&D funding for the improvement of U.S.-owned defense-related CRT technology.

The widespread use of flat panel technology in defense systems is several years in the offing, and will only gradually replace the use of CRT systems. Meanwhile, CRT display technology continues to evolve rapidly to accommodate the growing complexity of commercial and defense information systems. The U.S. CRT production base remains weak and fragile, but its demise would undercut the supply base for an important defense system.

- High-Resolution Systems. DARPA should work with the National Institute of Standards and Technology to encourage the early establishment of standard sizes and electronic interfaces, in order to allow manufacturers to prepare for

future markets in flat panel displays and to undertake necessary investments. The establishment of standards will help create a vertical market in the United States and encourage the development of advanced display technology.

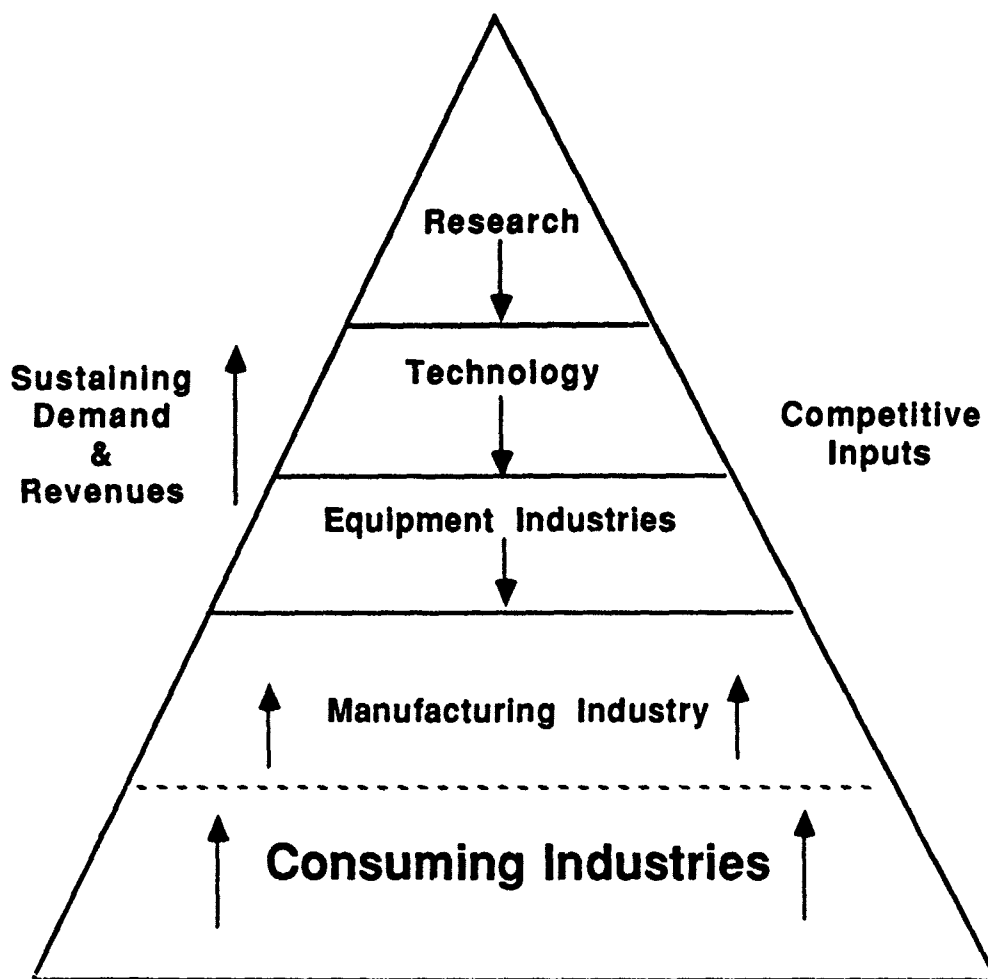
Coordination with the National Institute of Standards and Technology (NIST) to encourage the early setting of standard sizes and interfaces is critical, both to stimulate the industry to develop the technology and to create a market for advanced display technology. Increased DARPA R&D efforts in high-resolution systems appear crucial for future U.S. independence in defense information displays. However, these R&D effort must be strongly coupled with measures to assure the development of U.S. production and system integration capabilities.

B. MAIN COMPONENTS OF A DEFENSE RESEARCH STRATEGY

1. Key Considerations

A pattern of U.S. industrial erosion that has become familiar from the textile, steel, consumer-electronics, ball-bearing, and machine-tool industries, and is now evident in the microelectronics industry as well, is that they have receded from the base upward. Attrition of the *consuming* (e.g., consumer electronics) *industry* base, combined with faster growth of demand abroad and failure to maintain export competitiveness, leads first to a weakening of the *production* (e.g., semiconductor) *industry*. A production industry base decline, in turn, undermines the (semiconductor) *equipment industry* supplying it. In short-term-oriented U.S. firms, R&D funding is often one of the first items to be cut as profits decline. Over time, as domestic production industry demand for improved technologies falls off, technology migrates with the rest of the industry to faster growing supplier and market bases abroad.²⁰ *Ultimately, a meaningful research strategy must assure that a healthy consuming industry base is being maintained, or the underlying technologies cannot remain vigorous and viable under present conditions of world competition.* These interdependent relationships are illustrated in Figure III-1.

²⁰ Traditionally, a firm could maintain economies of scale and competitiveness by expanding exports. However, in recent years, interventions by the governments of foreign competitor nations to promote their domestic industries and exports and to protect their markets, combined with a strong dollar and weak export orientation in many U.S. industries, have negated much of that potential. Such foreign government intervention often targets defense and high-tech industries.



If the base erodes, the upper tiers cannot survive.

Figure III-1. Industrial Base--Essential Support for R&T and Equipment Industries.

A conclusion that flows from this pattern is that research money and effort from government sources such as DARPA for defense or dual-use industries with an eroding domestic market base may produce only short-lived benefits for the U.S. technology base, unless erosion of the domestic consuming base is also reversed. In fact, given the growing foreign acquisitions of U.S. high-technology industries, the benefits of DARPA research for U.S. defense may be lost more quickly in some cases by foreign acquisitions than by the loss of markets by domestic producers. Since defense requirements are often only a small percentage of industry sales, DoD is often seriously limited in how much it can contribute by itself to improve commercial market vitality.

2. Recommended Approach

In technologies where reducing the risks associated with foreign sourcing appears vital, DoD should work with others in government and industry to improve the market viability of research technologies and to reduce procurement and other policy-imposed cost burdens which undermine their development and market viability.

To enhance prospects that an advanced research strategy would strengthen the defense technology and industrial base requires a major coordination effort. The steps of such a strategy include:

1. The establishment of an effective system of monitoring global leadership trends in key defense technologies, to supplement evidence from this and other system-based studies in assessing challenges to U.S. technology leadership.
2. Work with OSD and the armed services to monitor trends in foreign sourcing in selected technologies, with particular emphasis on the sourcing of key production and test equipment which may serve as leading indicators of technology trends.
3. The development of an initial list of research priorities based on a broad technology monitoring and assessment system (step one), supplemented by an assessment of sourcing trends identified in system- and equipment-based studies (step two). Establish an ongoing system for assessing foreign sourcing risks.
4. The persuasion of USD(A) to set up a task force to develop a coordinated DoD-wide approach supporting DARPA research initiatives. This effort should emphasize ways in which improved acquisition policies can assist in strengthening the supplier and market base of the underlying defense industries in priority technology areas.

C. ASSESSING FOREIGN TECHNOLOGY SOURCING

1. Overall Conclusions

- The Need for a Broad Perspective. The present range of defense-relevant technologies being developed is so vast and diverse and involves such great expense that *no nation can even compete, let alone lead, in all the technologies key to future defense supremacy.* Few nations are able to sustain efforts in a wide variety of defense technology research. Fewer still have a defense program sufficiently large and diverse to provide them the potential or to establish a need for broad-based R&D efforts in defense technologies.

- Data. Lack of systems to track the sourcing of parts and components makes it difficult and costly to determine the extent, let alone the significance, of defense system sourcing of foreign technologies. Both the extent of foreign sourcing and the effort required to identify it expand as tracking moves down the supply chain.
- Alternative Sources. It was beyond the scope of this study to determine to what extent additional domestic sources might be available and competitive if greater effort were placed on easing military specifications or procurement standards.
- Foreign Ownership. The study failed to find a reliable or comprehensive database or system for determining the nationality of ownership or principal financing of U.S. defense system suppliers.
- Procedural Effects. Many DoD acquisition rules divert sourcing choices from consideration of "the best technologies," causing domestic sourcing in some defense systems to be higher than it would be if technological quality mattered most.
- Source Tracking. Improvements in tracking foreign parts and components sourcing would be very costly and could be justified only for uniquely critical weapons systems. An effort to develop a system to assess trends in global leadership in key defense technologies would be more productive and less costly for planning an advanced research strategy.
- Equipment. At the system level, findings on the sourcing of production, assembly, and testing equipment appear to be the most informative and meaningful in identifying and foreshadowing technologies where the United States may face the greatest foreign sourcing risks in the future.

2. Overall Recommendations

- Technology Assessments. DoD should encourage the development of a Government-wide program for the comprehensive, systematic assessment of global trends in key defense technologies, including comparisons of U.S. technology advances with those of other leading countries. Special attention should be given to identifying those in which leadership is moving offshore and concentrating in one or a few countries. Such an assessment system is needed to supplement studies of system and equipment sourcing.
- Study Equipment Sourcing Patterns. DoD should study patterns in foreign sourcing of *production, assembly, and testing equipment* by defense industries to improve its assessment of emerging areas of foreign technology dependence.

- Foreign Ownership. OUSD(A) should initiate support for work now under way which could bring about a comprehensive and efficient database system for identifying and monitoring foreign ownership and changes in ownership of U.S. defense industry suppliers.

D. FINANCIAL PROBLEMS AND PRACTICES

Concerns expressed most frequently by defense system contractors interviewed about industry's ability to meet DoD technology requirements were those relating to the cost of capital, difficulties in obtaining defense R&D funding, tax rules, and accounting requirements which, contractors maintain, needlessly limit R&D and investment resources.

1. Conclusions

- Industry Health. Findings of this and related studies emphasize that, to assure healthy U.S. defense technologies, R&D support is not enough if (a) the firms developing the technologies are too small to be viable without foreign capital,²¹ or (b) if their combined domestic commercial and defense markets are eroding while offshore markets and suppliers are healthy and growing.
- R&D. The need for tax and other incentives to encourage the R&D and long-term investments required for revitalizing capital-intensive industries such as equipment manufacture is supported by contractor comments in several studies.

2. Recommendations

- Investment Incentives. USD(A) and DARPA should develop legislative proposals to provide incentives to stimulate long-term investment in key defense and dual-use technologies, with preferences to those using U.S.-sourced equipment. Provisions considered should cover a broad range of options, including tax incentives and lease-financing. Proposals should emphasize incentives that best encourage equipment production in high-tech industries generally, and in machine tools, flat panel technology, and semiconductor manufacturing in particular.
- Supportive Acquisition Policies. DARPA should reinforce the effectiveness of its research priorities by coordinating them with other USD(A) agencies to assure that their acquisition policies enhance the market viability and international competitiveness of firms that provide U.S. technology leadership.

²¹ For a recent exposition of this point see Clyde V. Prestowitz, Jr., "Big Versus Little," *Business Month*, April 1989, pp. 58-64.

- Pilot Coordination Effort. To develop an effective system of coordinating these priorities, DARPA should propose to undertake jointly with other USD(A) agencies a pilot effort to coordinate acquisition objectives with research priorities in one key equipment technology such as machine tools.
- Direct IR&D Funding. IR&D funds are included as an allowable cost against contracts to a system prime contractor, but they generally do not find their way from prime contractors down to subtier contractors to fund IR&D in manufacturing, equipment development, or processing and development of advanced materials. USD(A) should modify procedures to encourage direct subcontractor funding for these purposes.
- Development. In future R&D contracts, DARPA should follow up with armed service program managers to see that provision is made in development programs to ensure adequate support for investment in manufacturing capability for the technologies being developed.
- Investment Tax Credit. OSD should support legislative efforts to make permanent the federal investment tax credit.
- Depreciation Allowance. USD(A) should push for legislation that allows accelerated depreciation of production and process equipment required in defense-critical advanced technology industries. Such allowances might be made preferential for U.S.-made semiconductor equipment and machine tools, and might further be scaled to the U.S. content (excluding raw material) in this equipment.

U.S. equipment depreciation schedules currently are tied more to the physical life of equipment than to the economically or competitively useful life of the equipment. DoD's aim should be to seek reorientation of U.S. depreciation allowance schedules to a "competitive life" basis, especially for industries in which technology evolution is very rapid. Depreciation terms preferential to U.S.-made equipment in defense-critical industries might be justified, but only for a limited period of years and only as a means of keeping what remains of these U.S. industries intact until effective revitalization efforts can be developed with U.S. industry leadership and government cooperation.

- Program Incentives. USD(A) should establish program incentives for system vendors to cooperate with U.S. tool manufacturers in improving U.S. machine tool capabilities where they are currently lacking. In addition, USD(A) should consider contractual provisions that encourage accelerated modernization of vendor facilities to stimulate the revitalization of U.S. machine tool industries serving defense requirements.

E. DEFENSE ACQUISITION POLICIES AND PRACTICES

The following are leading DoD acquisition issues raised by contractors in the course of the four system studies. These are areas for priority attention as a second dimension in support of a DARPA research strategy--a dimension that requires the increased cooperation of acquisition authorities. Issues that cut across several systems are listed first, followed by issues raised in the context of specific studies.

1. Overview

This study concludes that a majority of the technologies in which growing foreign sourcing was identified involve declining U.S. defense supply capabilities in established technologies where the United States once held a leading or competitive position. Among the reasons for the decline of these capabilities were: (a) reduced U.S. competitiveness and share of world markets, (b) related foreign gains in engineering and manufacturing capabilities and in market power, (c) segregation from commercial product lines of production for defense systems, and (d) increased costs of doing defense business.

Reduction of foreign sourcing of *established or mature technologies* would depend primarily on actions to reduce U.S. supplier costs of defense acquisition and to clarify confusing policies affecting foreign sourcing. DARPA research efforts may be applicable, but only in a few areas of concentrated foreign sourcing in *advanced materials*. Accordingly, the following conclusions and recommendations focus on acquisition cost and policy issues.

a. Conclusions

- **Conflicting Guidance.** Two "sets" of laws and regulations influence sourcing decisions. One encourages use of offshore sources to promote cost competition and allied cooperation. Another limits use of offshore sourcing out of concern about the U.S. defense industrial and technology base.
- **Sourcing Decisions.** Present acquisition policies allow program managers considerable flexibility in sourcing decisions. Program managers often have leeway to choose between permitting or precluding foreign sourcing, resulting in wide variations in foreign sourcing from system to system. Program objectives such as specifications, schedule, cost, quality assurance, and alliance relationships are key decision factors. Program cost reduction pressures often shift the balance of decisions toward offshore sourcing, in conflict with efforts to strengthen the U.S. technology base.

- **Acquisition Problems.** Acquisition problems encountered by contractors in their view needlessly increased costs and reduced profits from defense business or created problems and frustrations that discourage suppliers from continuing in the business.

b. Recommendations

- **Rationalize.** OSD, with DARPA assistance, should provide program managers added guidance to help them decide which of the various competing policies and practices affecting sourcing they should use, according to the circumstances that dominate in their programs. This guidance should take into account and support the possibilities for domestic sourcing of technologies being fostered by DARPA or IR&D funding. OSD should work with Congress to simplify laws affecting foreign sourcing.
- **Avoiding Risk.** USD(A), in consultation with DARPA, should establish a forum (a) to decide which defense technologies moving offshore are critical, (b) to evaluate the potential risks of increased offshore sourcing, and (c) to develop strategies to mitigate the risks, with emphasis on aligning acquisition policies in support of research priorities.

2. Specific Acquisition Issues

Contractors cited numerous acquisition policies and requirements as having an adverse impact on domestic sourcing of system parts, components, and technologies. Concerns focus primarily on the costs of contract burdens and of complying with acquisition requirements. Contractors maintain that high, and arguably excessive, costs and special conditions imposed by defense procurement procedures reduce the number and competitiveness of domestic suppliers, thus contributing to increased reliance on foreign sources.

In some cases, these conditions apply only or mainly to domestic suppliers. A prime example cited is the Government exercise of rights to proprietary data used for soliciting second sources to compete with the initial developer--a requirement that is frequently given as a factor in causing U.S. firms to quit the defense business. A second example, in microelectronics, involves a debate whether to qualify overseas locations for the Qualified Manufacturers List or QML (certifying as MILSTD all defense products from those facilities) could result in greatly increased offshore procurement of MILSTD devices.

Many of these requirements may also apply to procurement from foreign sources, but they have exceptional effects on domestic sourcing. First, these requirements often

cause program managers or subcontractors to use alternative procurement procedures that reduce costs and complexities. An example would be a cost-based decision to procure MIL-STD-883 semiconductor devices (which have much less rigorous requirements and are much more economically obtained offshore) instead of costlier JAN parts produced in the United States. Second, these requirements often have a higher unit-cost burden on smaller contractors, reducing their profitability and interest in defense contracting. The result is to increase the advantage and market share of larger, more integrated firms that can more easily absorb these costs, among which firms are many foreign suppliers.

The following subsections present conclusions and recommendations on specific acquisition issues.

a. Cost Accounting Practices

- Council Review. The Defense Acquisition Regulation Council should accelerate and intensify efforts to reduce burdensome cost accounting practices.

Separate cost accounting practices for defense systems increase the cost of doing defense business and, in combination with differing product standards and other requirements, have caused or forced many manufacturers to segregate commercial and defense production lines. Such segregation sharply reduces economies of scale and raises unit costs for defense production items. Among other measures, early decisions by the Defense Acquisition Regulation Council to cut detailed cost and pricing data requirements could help reduce the costs of MILSPEC parts and improve the U.S. defense technology base by improving the competitive position of U.S. products vis-à-vis offshore products.

b. Military Standards and Specifications

(i) Conclusions

- MILSPEC. A primary factor keeping the bulk of defense microelectronics parts, packaging, and assembly (and, to a lesser degree, wafer fabrication) onshore is DoD's requirement for MILSPEC parts.
- Sourcing Trends. The sourcing of microelectronics parts is shifting away from MILSPEC devices, fabricated and assembled domestically, toward MIL-STD-883-screened devices that are predominantly assembled offshore. This trend reflects reduced adherence to existing order-of-precedence policies for sourcing microelectronics devices.

- **QML Initiative.** A DoD decision to authorize Qualified Manufacturers List facilities in foreign locations could result in extensive increases in the offshore sourcing of defense microelectronics. Such a decision could have adverse consequences on the remaining U.S. microelectronics equipment industry and on such efforts to revitalize onshore microelectronics production and equipment capabilities as SEMATECH.

Proposals to allow the certification of offshore "Qualified Manufacturers List" facilities, if taken in combination with a provision to establish an order of precedence for microelectronics procurement that treats QML and JAN devices as equivalent, would virtually eliminate these two important factors keeping fabrication and assembly operations onshore. The alternative of restricting QML to onshore facilities would reduce the average unit cost of quality assurance certification and would help make domestic microelectronics more competitive with offshore products, since such nonrecurring costs can be amortized over greater volumes.

There is virtually no incentive for primes or DoD program offices to spend more per unit for MILSPEC parts than for 883-screened parts. Thus, without enforcement of procurement precedences favoring MILSPEC parts, the percentage of onshore production would decline markedly.

(ii) Recommendations

- **High-Tech Policy Review.** DARPA should propose a joint review, with the Under Secretary for Acquisition, of current policies on (a) microelectronics sourcing precedence, (b) plans for QML certification, and (c) objectives of SEMATECH and other research efforts to revitalize onshore U.S. microelectronics capabilities. The goal would be to coordinate objectives in these three and possibly other related areas to assure that they are mutually consistent and supportive.
- **QML and Precedence Policies.** *As an interim measure*, as part of a broader microelectronics industry revitalization strategy, USD(A) should (a) limit QML eligibility in microelectronics to onshore production and (b) consider directing the armed services to enforce existing policies on order-of-precedence in microelectronics sourcing for weapons systems. Such policies would be "survival insurance" for the near term until IR&D and other revitalization efforts restore industry competitiveness.

c. Export Controls

- **Study.** USD(A) should request a Defense Science Board study to investigate the impact of export control restrictions on U.S. defense manufacturers' ability to compete with offshore sources, as well as the advantages gained by foreign competitors and the significance of those advantages.

Cases have been identified in which export control restrictions give offshore competitors time to develop and market competing products free of competition from U.S. suppliers. To the extent that export controls limit sales to offshore markets, they reduce sales volume and price competitiveness. R&D funding and facility upgrades, which depend on investment returns, are undercut by lost revenue.

F. INDIVIDUAL SYSTEM FINDINGS

The foregoing study report presents consensus views of the study teams on recommendations that have general applicability. The system studies in Appendix B, prepared by four separate study teams, are presented as submitted by those teams. They include recommendations that address in more detail specific findings and recommendations specially applicable to the particular systems studied.

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APPENDIX A

TASK ORDER AND VULNERABILITY FACTORS

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Annex II--Vulnerability Factors.....	A-II-1

APPENDIX A, ANNEX I
PROJECT ASSIGNMENT A-135



DEFENSE ADVANCED RESEARCH PROJECTS AGENCY
1400 WILSON BOULEVARD
ARLINGTON, VA 22209-2308

ASSIGNMENT FOR WORK TO BE PERFORMED
BY
INSTITUTE FOR DEFENSE ANALYSES

PROJECT ASSIGNMENT NO. A-135

DATE: JUL 26 1989

You are hereby requested to undertake the following task:

1. **TITLE:** Defense System Dependency on Foreign Technologies

2. **BACKGROUND:** Evidence of increased U.S. defense dependence on foreign technologies has grown, but relies mainly on a few highly specific case studies, supplemented by anecdotal indications arising from random rather than systematic investigations. If such U.S. dependencies do represent real vulnerabilities in the nation's ability to support or improve its defense capabilities, then DoD is responsible for determining the severity and extent of these vulnerabilities and for appropriate action to reduce them. Needed first, however, is a systematic quantification of the nature, extent, and severity of any such dependencies and any associated vulnerabilities, assessment of their significance, and consideration of the need and feasibility of actions or programs to remedy them. For this purpose, DARPA is initiating a four-part study of Defense System Dependency on Foreign Technologies (a) to help it determine if existing or prospective defense technology dependencies are sufficiently great to justify its developing a strategy to reduce these U.S. foreign-technology-dependence vulnerabilities, and (b) to provide a quantitative and analytical base for developing a strategic plan. The study will consist of four Parts, each assigned to a separate organization, including:

Part I: A compendium of laws, policies, and regulations that affect the extent and degree of U.S. defense system dependency on foreign technologies, and an assessment of the impact of each on defense dependencies.

Part II: A narrative summary and index of current and historic instances of technology denial as a means of leverage, along with an assessment of the impact of this denial, to include instances of foreign as well as U.S. denial to others.

Part III: Identification and quantification of critical dependencies; determination of associated vulnerabilities, and assessment of their significance in terms of defense capabilities.

Part IV: Assessment of the criticality of various vulnerabilities; assess those most critical and identify alternative means of avoiding or reducing their impact, and actions or programs DoD can undertake for remediation where critical vulnerabilities cannot be avoided.

IDA is to conduct Part III of the study, but to participate in other Parts as appropriate and feasible.

3. OBJECTIVE: The objective of this task is to assist DARPA to accomplish the purposes of this four-part study. Specifically, this requires IDA to identify the extent and nature, and to quantify the importance of U.S. defense dependence on critical foreign technologies, and to assess their significance for the defense capabilities which these dependencies affect. In addition, it should contribute to other Parts of the study as its expertise, time, and resources permit.

4. STATEMENT OF WORK:

a. In consultation with DARPA, IDA will review leading areas of apparent U.S. defense dependence on foreign technologies. Before August 1, 1989 IDA will provide DARPA with a recommendation and justification for cases proposed to be studied in detail. With DARPA concurrence, IDA will select for detailed study some number and combination of technologies and weapons systems, emphasizing in selection those that are most representative of the nature and extent of U.S. dependencies in other weapons systems, and that involve technologies or materials important in a broad range of defense applications.

b. In the case studies, IDA will provide quantitative measures of the extent of dependency and vulnerability for each defense technology studied, and assess the nature and significance of the dependency. The case studies should define dependency in terms that are measurable, and should define and differentiate vulnerability from dependency in each case. To the extent feasible, it should also develop separate quantitative measures of vulnerability where appropriate. In seeking quantifiable measures, IDA should pursue several approaches in data collection, which may include among others approaches on a company, weapons system, and technology-supplier basis.

c. In defining "dependency" on foreign technologies, the study should also evaluate whether "foreign" should include: (a) foreign-owned firms located in the United States, (b) U.S.-owned firms supplying DoD from abroad, (c) U.S.-foreign joint ventures, whether located in the U.S. or abroad.

5. SCHEDULE: IDA will meet monthly beginning August 1, 1989 with representatives of DARPA and contractors assigned other parts of this study to provide progress briefings on the definition and implementation of this task. IDA is to supply a final draft report by November 1, 1989, and a final report 30 days after sponsor review and approval.

6. TECHNICAL COGNIZANCE: Technical cognizance for this task order is assigned to Lisa M. Niesz, DARPA, Office of the Director, Tel. 694-1139.

7. FUNDING: For this task, \$184,000 is authorized for FY 1989 and \$65,000 is authorized for FY 1990.

Project Assignment No. A-135

8. REPORT DISTRIBUTION AND CONTROL: The Director, ~~Defense Science Office~~, DARPA, will determine the number of copies of reports and their distribution. A need-to-know is hereby established in connection with this task and access to classified documents and publications, security clearances, and the like necessary to complete this task, will be obtained through the Director, DARPA.



CRAIG L. FIELDS
Director

ACCEPTED: 

W. Y. SMITH
General, USAF (Ret.)
President, Institute for Defense Analyses

DATE: 11 July 89



DEFENSE ADVANCED RESEARCH PROJECTS AGENCY
1400 WILSON BOULEVARD
ARLINGTON, VA 22209-2308

ASSIGNMENT FOR WORK TO BE PERFORMED
BY
INSTITUTE FOR DEFENSE ANALYSES

AMENDMENT NO. 1
PROJECT ASSIGNMENT NO. A-135

DATE: 24 JAN 1990

You are hereby requested to undertake the original task, as hereby amended:

1. TITLE: Defense System Dependence on Foreign Technologies
4. STATEMENT OF WORK: Add:

d. In reaching agreement on the weapon system cases proposed to be studied, per section 4.a. of the Statement of Work, IDA has agreed to DARPA's request that it study four types of systems, on a "best efforts" basis, instead of the two IDA originally proposed. This additional effort requires more FY 1990 funding than originally provided, needed at this time to permit IDA to implement DARPA requests for improvements to the draft final report, to conduct peer and expert review, and to make final submission of the completed report.

6. FUNDING: Change:

To complete this task, the original task fund amount of \$249,000 is increased by \$60,000 of FY 1990 funds.


CRAIG L. FIELDS
Director

ACCEPTED: 

W. Y. SMITH
General, USAF (Ret.)
President, Institute for Defense Analyses

DATE: 1 Dec '89

APPENDIX A, ANNEX II
VULNERABILITY FACTORS

VULNERABILITY FACTORS

LOCATION FACTORS

1. Transportation exposure Is *transport* susceptible to disruption from nonmilitary causes (e.g., weather, natural disasters)?
2. Natural disturbances Is *production* susceptible to disruption from *prevalent* natural causes (e.g., freezing, hurricanes, floods)?
3. Geographic concentration Are sources strongly concentrated geographically?

POLITICAL-MILITARY FACTORS

4. Political tensions Could ideological or political differences potentially generate political interference with supplies?
5. Internal political stability Are civilian political action groups or insurgent forces likely to disrupt supplies by direct action?
6. Regional political stability Are unfriendly political or military forces near a supplier country able to disrupt supplies by direct action?
7. Defense capabilities Are U.S., country, or regional defense forces limited in their ability to assure supply in times of country or regional instability or hostilities?

ECONOMIC-COMMERCIAL FACTORS

8. Economic stability Could source countries' debt, exchange controls, or monetary, labor, or other economic instabilities disrupt supply?
9. Trade stability Are suppliers dependent on imports that might be subject to interruption or interdiction?
10. Regulatory environment Is regulatory environment (trade, investment, environment, etc.) subject to disruptive or frequent change?
11. Business practices, ethics Are business practices (QC, standards, contract enforcement, etc.) and ethics inferior to U.S. levels?

SUPPLY AND TECHNOLOGY FACTORS

- | | |
|------------------------------------|---|
| 12. Domestic availability | Do U.S. producers lack a viable technology or a production base for supplying it? |
| 13. Economic concentration | Does supply depend heavily on a few sources? |
| 14. Supplier strengths | Are suppliers susceptible to failure or contract default from declining market position or competitiveness, debt, high capital costs, performance shortcomings, etc.? |
| 15. Item substitutes, alternatives | Is it hard to develop substitute or alternative defense technology solutions or applications? |
| 16. Commercial markets | Does the U.S. lack equivalent or comparable technology from defense and civilian applications? (dual use) |
| 17. Source alternatives | Is it hard to acquire or develop alternative technology or item suppliers? At what cost? Delay? (surge) |
| 18. Technology dynamics | Is the technology mature, stable, and unchallenged by alternatives or substitutes? |

PROCUREMENT AND PROGRAM-CONTROLLED FACTORS

- | | |
|------------------------------|--|
| 19. Buyer power | Are program orders a small percentage of suppliers' business? |
| 20. Purchase terms | Do DoD purchase terms discourage supplier competition? Hard to improve U.S. supply security? |
| 21. Stockpiling | Is it hard for program budget and storage technologies to support life-of-type buys and storage? |
| 22. Specification adjustment | Is it hard to modify product or test specifications to increase supply security or alternative supply sources? |
| 23. Procurement requirements | Is it hard to modify procurement requirements to increase supply security or alternative supply sources? |
| 24. Defense cooperation | Do lack of integrated defense missions, interoperability, standardization, or other cooperative arrangements limit supply security, reliability? |
| 25. Program support | Is there a lack of DoD or private sector programs working to develop alternative technologies? |
| 26. Engineering solutions | Is it hard to engineer around the vulnerable technology? |

APPENDIX B

INDIVIDUAL SYSTEM STUDIES

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APPENDIX B, ANNEX I

AIRCRAFT DISPLAYS

John P. McHale

Stephen N. Wooley

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EXECUTIVE SUMMARY

The purpose of this study of aircraft cockpit displays is to determine whether foreign technology is important in their current and future production, and whether foreign technology sourcing represents a significant vulnerability for U.S. defense systems. For this purpose, cockpit displays of several widely used U.S. aircraft were chosen and sourcing information was obtained on their displays. With the emergence of flat panel technology, cockpit designers can consider flat panel as well as the traditional cathode ray tube (CRT) displays. For this reason, sourcing data on both technologies was obtained. CRTs will only gradually be replaced by flat panel technology, which initially involves both higher costs and technical problems in adapting them to the high-brightness cockpit environment. To date, CRTs remain the best type of display for this environment. Among available types of flat panel technology, liquid crystal displays (LCDs) using thin film transistor switching circuits appear to be the most promising technical solution for cockpit use.

The foreign sourcing issue is germane to both CRT and flat panel technologies but for different reasons. CRT assembly and component production are shifting to foreign locations that have gained an edge in production costs and manufacturing quality in this established but still evolving technology. Meanwhile, U.S. manufacturers struggle to maintain a viable share of the world market from their few remaining onshore facilities. The U.S. initially led the world in CRT technology. By contrast, in emerging flat panel technology, U.S. R&D is seriously underfunded when compared to that of Japan and Europe.¹

The study found, at the R&D level, that differences in national leadership and commitments to high resolution systems are unfavorable to the U.S. and do not bode well for future U.S. technology leadership in this field. At the system level, the study found foreign sourcing of significant materials and components in cockpit CRT displays. Most

¹ This assertion was made by several of the manufacturers visited. Also, the Japanese lead in flat-panel technology is well documented in open literature. See "Computers: Japan Comes on Strong," *Business Week*, 23 October 1989, and "Flat Panel Displays Displace Large, Heavy, Power-Hungry CRTs," Lawrence E. Tannas, Jr., *IEEE Spectrum*, September, 1989, pp. 34-35.

such sourcing is due to the decline of domestic production capabilities, with few instances of special foreign technology advantages. For this reason, current sourcing could be replaced, at a cost, by development of domestic capabilities within periods ranging from roughly 6 months to something over a year in all but certain optical filters, filter glass, and glass bulbs. For the latter it could take several years and considerable expense to catch up with foreign technologies, retrain skilled personnel, and develop and qualify economically viable plants.

The limited scope of U.S. capabilities in flat panel technologies for defense systems appears more serious. Except for Litton-Canada, a U.S.-owned subsidiary, there is no U.S. LCD flat panel developer in North America with a clearly viable manufacturing capability, financial base, and proven system integration capability. Several other U.S. firms and labs have developed flat panel technologies, but have failed to establish them on a sustainable commercial footing. Several major European firm have begun to establish a manufacturing and R&D presence in the U.S., mainly through acquisition of American facilities. Whether they will become a significant factor in the future as suppliers of flat panel technology for DoD systems remains to be seen.

In seeking data for determining current levels of foreign sourcing in display manufacturing, the authors found no adequate overall defense tracking system or data bases on which they could draw. Nor is there any adequate database for determining national ownership of supplier firms, let alone their financing sources. Many U.S.-based vendors actually supply parts from foreign firms with which they have agreements. Thus, it is not enough to identify the plant location of the vendor to validate the country source of any part. As a result, these data gaps required part-by-part and company-by-company data searches to conduct the study.

Maintaining a U.S. display manufacturing capability down to the parts level does not appear economically viable at current DoD requirement levels, particularly under current dual-sourcing practices. Actual and potential U.S. manufacturers both gave lack of an adequate return on capital as their principal reason for not wanting to do business with DoD in this area.

I. INTRODUCTION

A. PURPOSE OF THE STUDY: THE PROBLEM

Over the past 10 years, anecdotal claims have been made within DoD and among system contractors that both display technology and production capability continue to migrate away from the U.S. Specifically in the manufacturing of displays, this transition occurred originally at the electronics level but eventually affected major display components such as the cathode ray-tube itself. Some see this migration as part of a broader shift away from applied technology and manufacturing toward a service-oriented economy. The purpose of this study is to investigate the sourcing of typical display systems in order to determine to what extent the U.S. retains the necessary technology parity or leadership in the manufacturing of displays and to what extent it has to depend on foreign sources.

B. FOCUS OF THE STUDY

1. Selection of the Systems

U.S. defense policy has traditionally counted on our technology advantage to offset numerical superiority of adversaries. An integral function of any defense system is to convey information effectively to its operator. As the technological demands on systems increase, so does the burden of informing the operator about the status of the system--position, readiness, etc. In order for the U.S. to maintain its technological advantage, displays must be able to relay growing amounts of important information in a wide array of defense systems. Displays were selected for study in part because of their breadth of defense applications.

Aircraft displays in particular were chosen for this study because of their broad application in both military and commercial aircraft. An aircraft cockpit requires a great deal of advanced technology in both design and manufacturing. There are different mission, functional, and environmental demands on aircraft displays. Cockpit requirements in fighter/attack (F/A) aircraft are different than those for patrol (P) aircraft. The process of selecting aircraft displays for study was constrained by the limited time,

manpower, and travel resources available. Selection emphasized aircraft using diverse and advanced display technologies. For this combination of reasons, the study focuses on displays manufactured for the F/A-18 aircraft, the AV-8B aircraft, and the P-7 aircraft, although information on other aircraft was obtained.

An added factor in selection of displays was that they are part of a broader family of high-resolution systems in which commercial applications are driving development of the technology. In view of broadly held perceptions in defense circles that increasingly such "dual-use" technologies are also leading development of key defense system technologies, it was judged important to include one such technology in the systems selected. As a dual-use technology, cockpit displays are a subset of a broader "High-Definition System" initiative within DoD.

2. Description of Display Systems

The components of any type of aircraft can generally be divided into three categories: airframe, engine(s), and avionics. Avionics is the commonly used term for all of the instrumentation needed for the aircraft to function and execute the specific mission it was designed to accomplish. Avionics equipment can be found in the cockpit, in equipment bays, or in specific-mission compartments of the aircraft.

Aircraft displays include a wide range of devices that provide aircraft crew members with information determined or transmitted by various sensors both in the air and on the ground. In terms of design demands, these displays can be divided into two types based on function and location. The primary use of displays is in the cockpit, where essential information such as navigation, flight control, radar, engine instrumentation, and some mission data is provided. In larger aircraft, other crew members may be in mission compartments to manage operations such as antisubmarine warfare, electronic warfare, surveillance, and rescue. Their displays, while larger in size, are not subject to the severe glare and lighting resolution problems that are found in the cockpit environment. Likewise, displays "in the rear" are not constrained by severe space limitations found in most cockpits.

In an aircraft, the most noticeable subgroupings of avionics equipments are normally referred to as displays. There are at least six types of displays that provide information to aircraft crews. In order of current worldwide commercial and military quantities, they are:

- (1) Panel meters and switches
- (2) Mechanical or electromechanical indicators
- (3) Cathode-ray tube (head-up and panel) displays
- (4) Map displays
- (5) Helmet-mounted displays
- (6) Flat panel displays.

We chose to assess cathode-ray tube and flat panel displays in this study.

Until the early 1960s, displays included only the first two types; driven either by internal sensors, servo-driven from remote sensors, or simply analog indicators of the status of some system. The advent of a third type of display using cathode-ray tubes (CRTs) caused a revolution in avionics architecture. Figure B-I-1 shows the components of a typical CRT. A critical component of CRTs is an iron oxide soft ferrite deflection coil (yoke). Aircraft designers could require multiple functions to be displayed to crew members, depending on what part of the mission they were performing. The TV-like presentation of data allowed the crew to clutter and declutter the various displays, depending on specific mission needs.

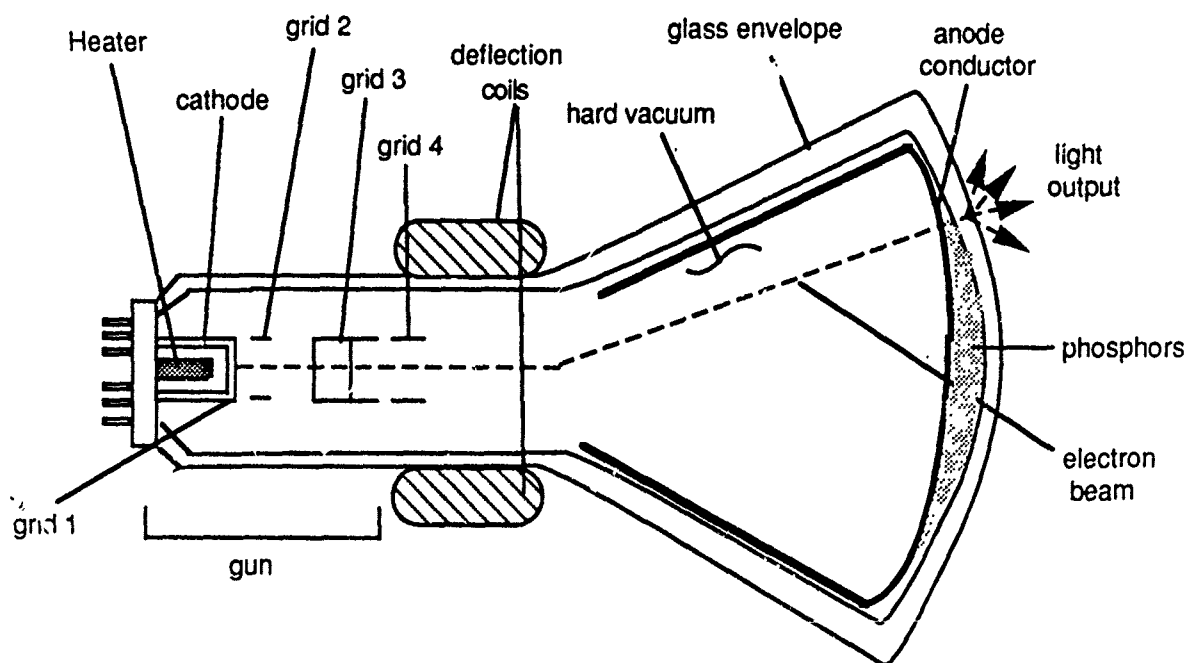


Figure B-I-1. Cathode-Ray Tube Diagram.

The concept of a head-up display (HUD) allows various flight information to be projected upon a combiner with a coating or hologram so the pilot can see the "outside real world" through the display or view the displayed information. Coatings are 50 to 75 percent transmissive, while holograms are 75 to 90 percent transmissive. HUDs use a digital computer to synthesize the data and a CRT projection system. HUDs give the pilot a "safer" view of the real world in which he was flying. Originally, only military aircraft used HUDs, but the use of HUDs in commercial aircraft has grown in recent years. These displays were initially monochrome, but full color displays have become available. Brightness, contrast, and resolution are required for a good color display to avoid glare and reflection problems. The major problem to overcome, the interference of sunlight on the display screen, is a significant technical obstacle.

The fourth type of cockpit display is the map display, a descendent of the knee board on which pilots kept track of their position. These range from a mechanical indexer (cursor) that moves over a real paper map to the latest type of interactive digital map displays. These newly available, fully digital devices are usually called multipurpose color displays. Although not a specific part of the display, the heart of many of the digital map display systems in the U.S. is an *optical memory storage disk that is made only in Japan*. It has been estimated that it would require an investment of about \$25 million to obtain this capability in the U.S. Although not part of a display, the memory disk represents a significant dependence.

The fifth type of electro-optic display is the helmet-mounted display. The small viewing portion of the outside world using a HUD is a limiting factor in the fighter-versus-fighter battle. Using a helmet display device, the pilot has full head-up capability. Weapon delivery and pilot awareness are enhanced relative to a conventional HUD and its small field of view. The helmet display can include ruggedized, high-resolution, electrostatic deflection CRTs. In addition to the presentation of radar data, displays can provide infrared data to give the pilot additional terrain features. Low-light-level amplification systems are also incorporated into helmet-mounted displays. The projection tube may be a miniature CRT. Only within the past few years have pilots had night vision goggle (NVG) helmet displays. However for certain military missions, they have proven to be invaluable and mission essential. The next generation of fully integrated, hybrid helmet displays has yet to be developed.

The sixth stage in the evolution of cockpit displays is well under way. The use of flat panel technology to replace the conventional CRTs is gradually becoming a reality. Flat

panel displays have become more numerous as a direct result of the amount of digital avionics replacing analog instrumentation. The recent shift in engine instrumentation displays from analog "steam gages" to flat panel displays is just one example. Flat panel displays will not totally replace CRT displays. Mission requirements and economic constraints will dictate the technology application.

C. APPROACH AND METHODS

After the initial selection of cockpit displays of the F/A-18, AV-8B, and P-7 aircraft, a visit was made to the Commanding Officer of the Naval Air Systems Command (NAVAIR), who has the responsibility of managing the Program Managers of the respective aircraft. Rear Admiral R.C. Gentz subsequently received a letter from DARPA providing details of the study. After briefing members of the respective program offices and personnel of the Avionics Division of NAVAIR, visits were subsequently made to the following sites:

<u>Organization</u>	<u>Location</u>
McDonnell Douglas Corp.	St. Louis, MO
Astronautics Corp.	Milwaukee, WI
Litton-Canada	Toronto, ON
Wright-Patterson AFB	Dayton, OH
Naval Avionics Facility	Indianapolis, IN
Kaiser Electronics	San Jose, CA
Naval Air Systems Command	Washington, DC

Other meetings were held with the President of the Society of Information Displays and the Chief of the Display Devices and Technology Branch, U.S. Army, Ft. Monmouth. Numerous telephone calls to industry and government personnel completed the process of data gathering.

The first visit was to McDonnell Douglas, the prime contractor for the F/A-18 and AV-8B. The principle Staff Director of Displays arranged for interviews with the F/A-18 Display Engineers for the HUD, the multipurpose display indicator (MDI), and the multipurpose display repeater indicator (MDRI) as well as F-15 display personnel. Subsequent meetings with Kaiser Electronics and Litton-Canada provided the main elements of the findings. Other data on the multipurpose color display (MPCD) was later furnished by the AV-8B personnel at McDonnell Douglas. The Astronautics visit and subsequent telephone calls to subvendors provided additional data. The meetings with

USN, USAF, and U.S. Army personnel proved invaluable as sources of corporate knowledge of where the display industry has been and where it might go in the future.

D. LIMITATION OF THE DATA SAMPLE

Litton-Canada provided a complete breakdown of the parts used in the production of the HUD, MDI, MDRI. These lists were later verified at Kaiser, the prime contractor. Both manufacturers build the HUD, MDI, and MDRI to the Kaiser prints for the F/A-18 and AV-8B. The MDRI will also be used on the F-14D and A-6F if these aircraft are approved for production. McDonnell Douglas provided a partial breakdown of the components in the MPCD made by Smiths Industries for the F/A-18 and AV-8B. A listing of McDonnell Douglas test equipment was also provided. Astronautics Corporation has not made a complete breakdown of the displays for the P-7 aircraft, since the aircraft is still in development. However, the manufacturer of the CRTs, Thomas Electronics, provided a complete breakdown of the foreign parts used in the P-7 CRTs and the CRTs for the F/A-18 HUD and MDRI. Table B-I-1 provides a summary of aircraft displays and manufacturers.

Table B-I-1. Aircraft Displays and Manufacturers

Aircraft	Display	Manufacturer	Technology
F/A-18	Head-Up Display	Kaiser/Litton	CRT
	Multipurpose Display Indicator	Kaiser/Litton	CRT
	Multipurpose Display Repeater Indicator	Kaiser/Litton	CRT
	Multipurpose Color Display	Smiths	CRT
	Horizontal Situation Indicator	Allied Signal/Ferranti	
AV-8B	Head-Up Display	Smiths	CRT
	Multipurpose Display Repeater Indicator	Kaiser/Litton	CRT
	Multipurpose Color Display	Smiths	CRT
P-7	Multipurpose Color Display	Astronautics	CRT
ATF/F-16	Multipurpose Color Display	Kaiser/Sextant	LCD
A-12	Multipurpose Color Display	Ovonic	LCD
F-15	Multipurpose Color Display	Honeywell	CRT

II. FINDINGS

A. SYSTEM SOURCING OF FOREIGN TECHNOLOGY

1. F/A-18 Aircraft

a. F/A-18 Aircraft Overview

The F/A-18 aircraft, developed by McDonnell Douglas and Northrop, has been in production since 1981. The F/A-18 has both a fighter and an attack mission operating from aircraft carriers. The single-pilot aircraft has been supplemented with a two-seat trainer version. There is also a two-seat night-attack version in development. A reconnaissance version using a pod is also in the fleet. The aircraft has been sold to Canada, Australia, Kuwait, Spain, and Switzerland. The five-per-month production rate for FY90 is a good example of second source impracticality for many of the components.

b. F/A-18 Display Overview

The F/A-18 aircraft displays consists of a Head-Up Display, the Multipurpose Display Indicator, the Multipurpose Display Repeater Indicator, and the Multipurpose Color Display. The latter is replacing the Horizontal Situation Display in earlier F/A-18 aircraft.²

(i) F/A-18 Head-Up Display

The HUD, an optical and electronic device that projects flight information in symbolic form into the pilot's forward field of view, was developed for McDonnell Douglas by Kaiser Electronics. The HUD has the capability to display attack, navigation, situation, and steering control information under all flight conditions. The CRT within the HUD is provided by Thomas Electronics.

² *Jane's Avionics*, 1987/8, p. 404.

(ii) F/A-18 Multipurpose Display Indicator (MDI)

There are two identical MDIs in the cockpit in single-seat aircraft. The MDIs provide:

- CRT display function
- 20 pushbutton request function
- Symbol and raster generation function
- Composite video interface with the radar/stores management sets
- Data bus interface with the mission computer
- Digital interface with the radar
- Digital and analog interface with the HUD
- Analog and digital interface with the other avionics
- Discrete/analog interfaces with instrument panel/throttle functions.

The MDI has a CRT manufactured by Hughes and all parts of the CRT are manufactured in the U.S.

(iii) F/A-18 Multipurpose Display Repeater Indicator (MDRI)

There are three MDRI in the back seat of the two-seat F/A-18. The MDRI provides:

- A CRT display function
- A 20 pushbutton request function.

The night-attack F/A-18 also further updates the MDI and MDRI for KROMA (red-yellow-green) stroke-only color capability. Also on night-attack aircraft, the horizontal situation indicator (HSI) is replaced with the MPCD. Forward-looking infrared imagery is available. Raster capability on the HUD is also available to display video information. The MDRI has a CRT obtained from dual sources: Thomas Electronics (U.S.) and Raytheon (U.S.).

(iv) F/A-18 Multipurpose Color Display (MPCD)

The Type 2100 MPCD was originally developed by Smiths Industries in Cheltenham, England, for the AV-8B Harrier aircraft built by McDonnell Douglas for the

U.S. Marines.³ The competitive procurement by McDonnell Douglas was awarded to Smiths Industries based on lower price and ability to meet the AV-8B program schedule requirements. The equipment is currently being integrated into the AV-8B during an aircraft avionics upgrade. Figure B-I-2 provides an exploded view of the MPCD. Note the relative depth requirement, which is typical for most CRT displays.

The MPCD is a full-color, high-resolution display that is viable over a wide range of ambient light conditions. Special filters provide compatibility with night vision goggles. The unit is claimed to be two times brighter than other shadow-masked cathode-ray tube displays. The MPCD has also been specified for the night-attack version of the F/A-18 as well as the British Harrier, GR-5. Other marketing efforts, such as a display for the F-14D and A-6F, are under way to increase the quantities for a more economical production run.

(v) F/A-18 Horizontal Situation Indicator (HSI)

The HSI was designed by Ferranti International in Edinburgh, Scotland, U.K. The HSI, however, is assembled by Allied Signal (Bendix) in South Montrose, PA, using Ferranti assemblies. The HSI foreign dependence was not pursued further because production will cease next year. This unit is being replaced by the MPCD in the F/A-18 night-attack version. Due to changing mission requirements for the AV-8B, the MPCD is replacing a monochrome display.

c. F/A-18 Sourcing of Foreign Technology

Kaiser obtains the filter glass and the filter for the HUD from Hoya (Japan). The glass is bought by lot and *Kaiser personnel estimated that it would take 5 to 6 years to get a U.S. capability because most advanced filter technology is located in Japan.* Corning used to be a supplier many years ago but ceased production because of low volume. Schott in Germany is an alternate source. Castings for the HUD and MDI are manufactured in Canada because of an F-18 offset between McDonnell Douglas and Canada. Kaiser and Litton get the CRTs from Thomas Electronics. Thomas Electronics obtains the glass bulb from Glaswerk Wertheim (FRG). A summary of HUD foreign-sourced parts is in Table B-I-2. Kaiser and Litton obtain the filter glass and filter for the manufacturing of the MDI from Hoya (Japan) and the remaining parts from the U.S. See Table B-I-3 for a summary.

³ *Jane's Avionics*, 1987/8, p. 370.

SMITHS INDUSTRIES
Aerospace & Defence Systems

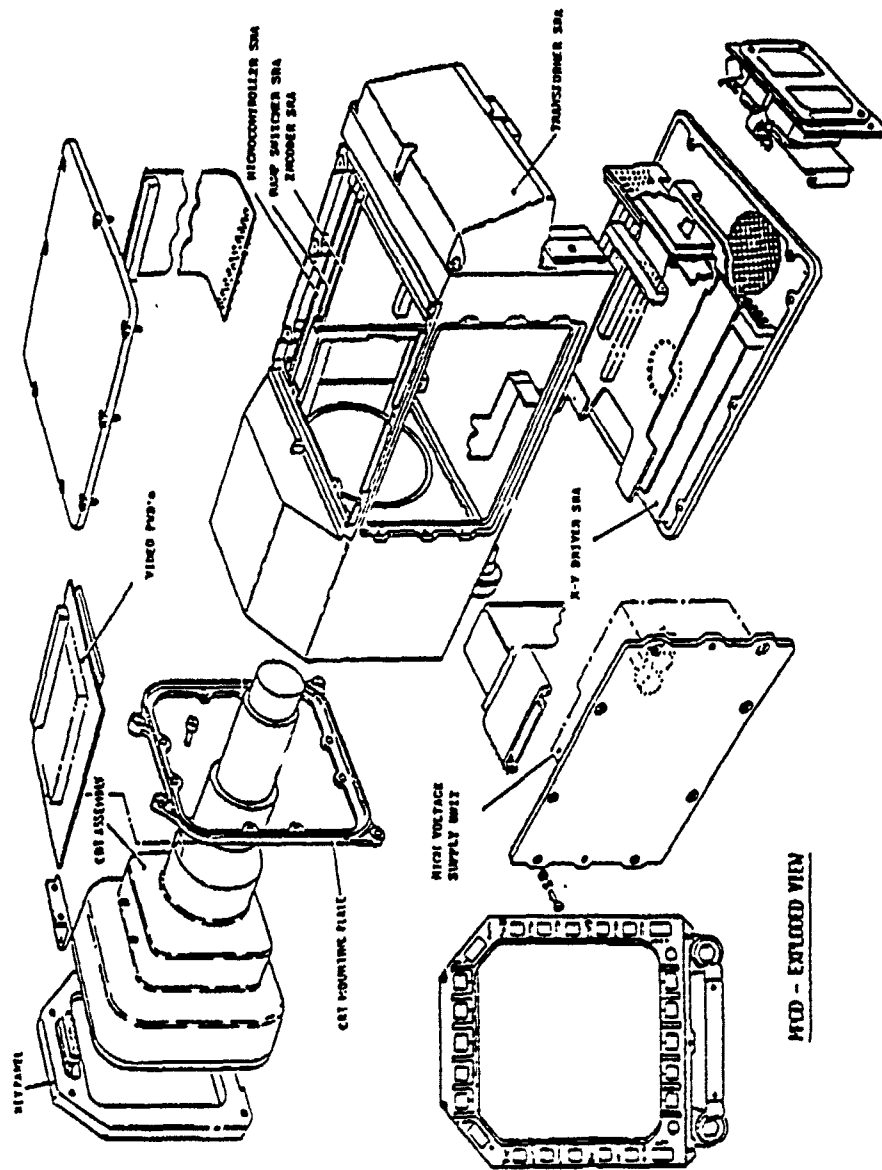


Figure B-I-2. Multipurpose Color Display (MPCD).

Table B-I-2. F/A-18 Head-Up Display Assembly Sourcing

Component	Vendor	Subcomponent	Quantity	Subvendor
Filter glass	Kaiser	N/A	1 ea.	Hoya (Japan)
Filter	Kaiser	N/A	1 ea.	Hoya (Japan)
CRT	Thomas Electronics	Glass Bulb	1 ea.	Glaswerk Wertheim (FRG)

Table B-I-3. F/A-18 Multipurpose Display Indicator Sourcing

Component	Vendor	Subcomponent	Quantity	Subvendor
Filter glass	Kaiser	N/A	1 ea.	Hoya (Japan)
Filter	Kaiser	N/A	1 ea.	Hoya (Japan)

Kaiser and Litton manufacture the MDRI with the CRTs from Thomas Electronics and Raytheon. The glass bulb for the Thomas Electronics CRT is provided by Sibascon (Japan). Raytheon stated that they were unaware of any non-U.S. components. Their vendor for the CRT coil assembly is a U.S. firm, Syntronic Instruments, Inc. However, according to Gardner N. Marcy, President and CEO of Syntronic, the molded ferrite coil is obtained from Nippon Ferrites, Japan. Nippon Ferrites supplies the cores for several reasons. First, they are willing to work with Syntronic in order to produce a custom-designed part. Second, they are willing to make the investment necessary to produce a component with a relatively limited lot size. Third, the complexity of the ferrite core rules out using any U.S. manufacturer as they are currently tooled. A summary of foreign sourcing can be found in Table B-I-4.

Table B-I-4. F/A-18 and AV-8B Multipurpose Display Repeater Indicator Sourcing

Component	Vendor	Subcomponent	Quantity	Subvendor
CRT	Thomas Electronics	Glass Bulb	1 ea.	Sibascon (Japan)
CRT Yoke	Syntronic	Molded Ferrite	1 ea.	Nippon (Japan)

Syntronic, which provides about 60 percent of all coils (yokes) for CRTs in the free world, relies exclusively on Japanese sources for its ferrite cores. This was not always the case. For over 20 years, Stackpole Carbon in St. Mary's, PA, was the principle ferrite source for Syntronic. In April 1987, as a result of ongoing labor problems, Stackpole went out of business. The cost to Syntronic for retooling with Nippon Ferrites (Japan) was around \$200,000; a large percentage for a \$6 million per year company. The company also had a second source from 1978 to 1984 in Indiana General, which was eventually sold to TDK (Japan), which terminated their ferrite coil business. Other ferrite sources are Fugi (Japan), Thomson CSF (France), and two Korean companies owned by Thomson. Syntronic continues to search for a second source.

Most of the components of the MPCD were developed by Smiths Industries (U.K.), which received R&D funds from the U.K. Ministry of Defense. A summary of foreign sourcing appears in Table B-I-5. The high voltage supply unit, cathode-ray tube, and key panel were bought in the U.S. from U.S. suppliers. Tektronix reported that they obtain the critical optical filter from Wamco (U.S.), which in turn obtains the filter from the Wakoh Corporation (Japan). Wakoh has the rights to use a unique domestically produced (in Japan) proprietary material to manufacture the filter. Thus this filter, which has a unique application in a color CRT, is obtained from Wakoh. The vendor for the CRT yoke assembly used in the MPCD is Syntronic. As noted above, Syntronic obtains their coils from Nippon Ferrites.

Two shop-replaceable assemblies (electronic cards) were developed by the Smiths Industries, Clearwater, Florida facility, which also provided some test equipment. Other support equipment was developed by McDonnell Douglas and other U.S. firms. The display is assembled in Cheltenham, England. However, Smiths personnel have indicated that the Clearwater facility could manufacture the entire MPCD, if required. Further analysis may prove this is questionable.

2. AV-8B Aircraft

a. AV-8B Aircraft Overview

The AV-8B aircraft, developed by McDonnell Douglas and British Aerospace (BAe), has been in full production since 1985. The original airframe and engine design for the AV-8A were by the same companies. That design had its origin in the original Harrier aircraft built by BAe in the U.K. The AV-8B (Harrier II) is a second-generation vertical/

short takeoff and landing (V/STOL) light attack jet aircraft produced for the Marine Corps. Currently, the United Kingdom and Spain also are using the basic aircraft. Italy has expressed an interest. The primary mission of the AV-8B is to provide responsive close air support for ground forces. The aircraft can operate from short fields, forward sites, roads, and surface ships providing minimum response time to target.

b. AV-8B Display Overview

The cockpit design of the AV-8B has gone through several iterations since the original BAe Harrier design of the early 1960s. Therefore, the current cockpit design is not that old. Cockpit displays consist of one Smiths (U.K.) HUD,⁴ two Kaiser Electronics (U.S.) MDRIs, and a Smiths (U.K.) MPCD. The MPCD was first integrated into the AV-8B and later the F/A-18, replacing the Allied Signal-Ferranti Moving Map Display.

c. AV-8B Head Up Display

No data was obtained on the Smiths HUD, although it is known that Smiths and the British Ministry of Defence have had a long association on the development of the system since the early 1970s. The technology for the HUD was developed in the U.K.

d. AV-8B Sourcing of Foreign Technology

The Kaiser and Litton MDRIs both have CRTs built by Thomas Electronics and Raytheon. Details of foreign-sourced components used by Thomas Electronics and Raytheon CRTs are provided in Table B-I-4. Refer to Table B-I-5 and the F/A-18 discussion for similar details of the MPCD.

Table B-I-5. F/A-18 and AV-8B Multipurpose Color Display Sourcing

Component	Vendor	Subcomponent	Quantity	Subvendor
CRT Optical Filter	Wamco	Optical Filter	1 ea.	Wakoh (Japan)
CRT Yoke	Syntronic	Molded Ferrite	1 ea.	Nippon (Japan)
CRT	Tektronix	Enhancement Filter	1 ea.	Shott (FRG)

⁴ *Jane's Avionics*, 1987/8, p. 422.

3. P-7 Aircraft

a. P-7 Aircraft Overview

The P-7 aircraft is currently being developed by Lockheed Aeronautical Systems Company. Initial operational capability is scheduled for 1993. Design and parts selection is still under way; parts approval submission to the government will occur in mid-1990. The primary mission is long-range air antisubmarine warfare capability aircraft (LRAACA). It is being designed to replace the current fleet operational P-3C aircraft for the U.S. Navy. A major design change from the P-3C is that the P-7 has a "glass cockpit" electronic display system (EDS) that replaces most of the existing P-3C electromechanical cockpit instruments. The EDS conveys essential flight, engine, and system warning information that is processed from other sensors on the aircraft. The EDS has functional fail-safe operational characteristics for all flight-essential data and has automatic and manual operational and test modes. Figure B-I-3 is a system block diagram of the P-7 indicating the interfaces of the various components of the EDS.

b. P-7 Display Overview

The P-7 has six high-intensity, high-performance, color-beam-index, cathode-ray tube display units (DUs). The DU designation is used by the system integrator in lieu of other designations (such as MPCD). The DUs have a 6.25 inch by 6.25 inch display. In addition, there are three symbol generators and other peripheral panels and controllers. Two DUs, one for each pilot, are used for primary flight information and two other DUs, also one for each pilot, are used for navigation data. The remaining two DUs are used for engine instrumentation and crew alert functions. The system integrator for the P-7 EDS is Astronautics Corporation of America. Astronautics, in turn, has awarded a contract for the CRTs to Thomas Electronics, Wayne, NJ.

Ferranti of the U.K. was originally teamed with Astronautics as the DU supplier, but Ferranti would not accept the terms and conditions of the Lockheed contract requirements after Astronautics won the award. Sony also failed to come to terms with Astronautics, citing the government of Japan's policy of not exporting military equipment as the reason. Satisfactory financial arrangements could not be determined with Tektronix. Finally, Thomas Electronics was selected.

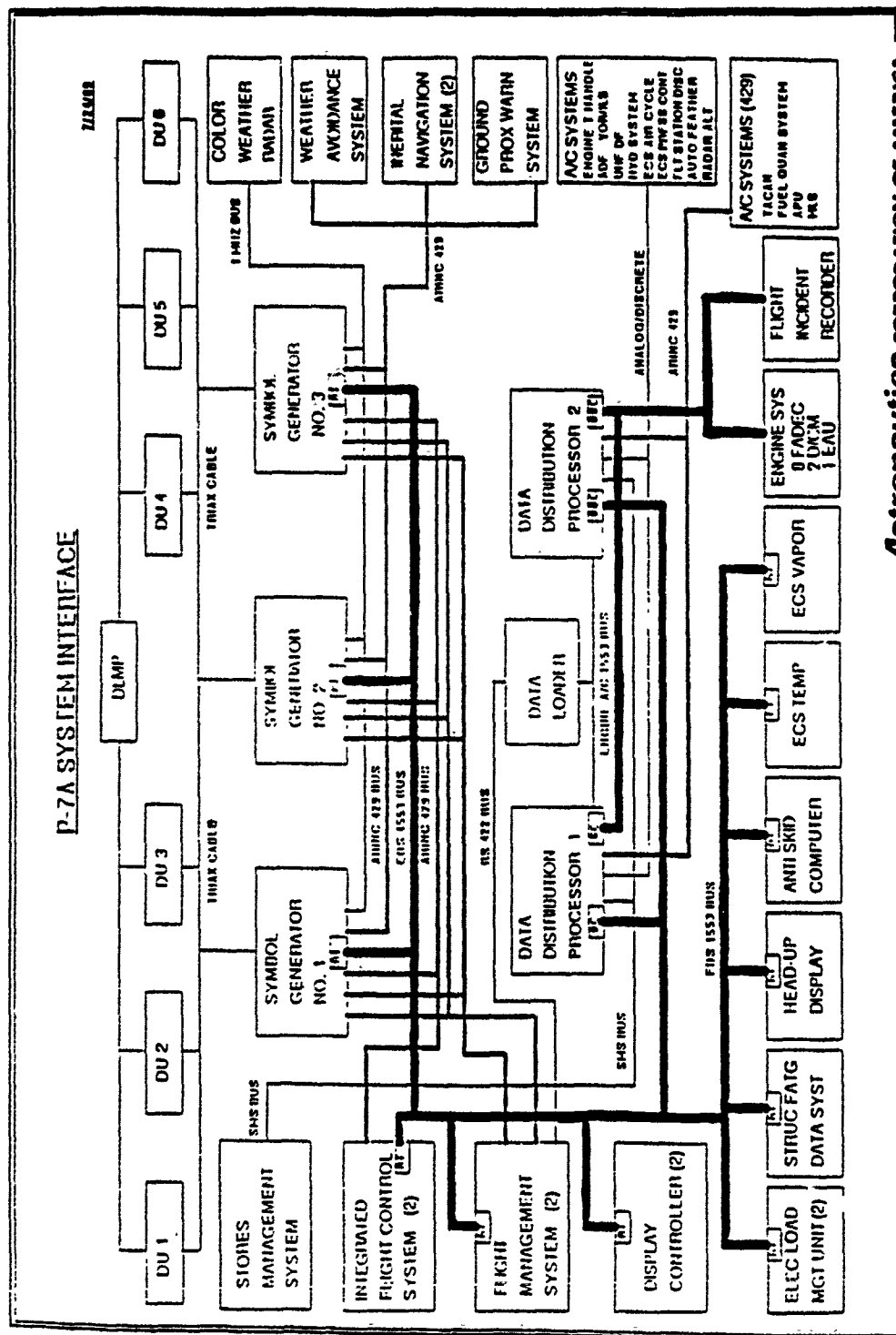


Figure B-I-3. P-7A System Interface.

Thomas Electronics manufactures over 4,200 types of video tubes, of which cockpit displays constitute the largest market. Funding from Astronautics was required to help the company adopt the technology for this specific program. The CRT for the P-7 uses color-beam indexing, which requires only one gun compared to three in conventional CRTs. Different phosphors are used to obtain the required color, but writing to the display is similar to that in a monochrome display. Beam current is reduced so that the display may not need forced air cooling, and the display is NVG compatible.

c. P-7 Sourcing of Foreign Technology

This study concentrated on the display itself rather than supporting electronics (Other segments of this report cover foreign sourcing of electronics technology). The CRT is the most critical and costly of the display components. The CRT is made up of components such as the glass bulb, deflection coils, phosphors, and cathode (Fig. B-I-1).

As indicated earlier, Thomas Electronics is purchasing some CRT components, such as phosphors, funnels, and faceplates, from foreign sources other than Canada. The phosphors are purchased from Nichia (Japan) and are superior to domestic sources because of luminous efficiency, uniformity, and usability. Should Nichia phosphors be unavailable, Thomas Electronics could purchase from a domestic or British source. However, desired quality standards may not be immediately met, but could be met in time.

Other critical items are the glass funnels and faceplates manufactured by Glaswerk Wertheim, Wertheim, Germany; Nippon Electric Glass (NEG), Osaka, Japan; and Sibascon, Tokyo, Japan. These companies have the molds which are necessary to fabricate these glass components. In case of a national emergency, these glass components could be tooled by Lancaster Glass Corporation of Lancaster, Ohio, provided appropriately skilled workers and tools are available. Data on these parts are summarized in Table B-I-6.

At one time Corning and later Lancaster Glass were the dominant suppliers of special-purpose bulbs for CRTs. However, due to lack of demand for electrostatic CRTs, Lancaster has closed down one production line which was exclusively producing hand-blown bulbs for electrostatic CRTs. Thus, after failing to convince DESC to make a one-time buy of the CRTs, Lancaster has focused exclusively on machine-pressed bulbs for electromagnetic CRTs. Lancaster and NEG together account for almost all of the bulb purchases by Thomas Electronics. Lancaster has faced increasing competition from foreign firms, particularly NEG. Lancaster claims that NEG has sold the bulbs at prices which

represent about 60 percent of manufacturing costs, but has not filed dumping claims. Corning made a corporate decision to get out of the business due to the low volume requirements. Making these CRTs was no longer an economical process. Additionally, Thomas Electronics purchases molds from Glaswerk Wertheim, NEG, and Sibascon. It would require 18-24 weeks for a U.S. supplier to meet Thomas Electronics' current demands in this area.

Table B-I-6. P-7 Multipurpose Color Display Sourcing

Component	Vendor	Subcomponent	Quantity	Subvendor
CRT of DU	Thomas Electronics	Phosphor-Red	30 grams	Nichia Chemical (Japan)
CRT of DU	Thomas Electronics	Phosphor-Green	30 grams	Nichia Chemical
CRT of DU	Thomas Electronics	Phosphor-Blue	30 grams	Nichia Chemical
CRT of DU	Thomas Electronics	Phosphor-Index	30 grams	Nichia Chemical
CRT of DU	Thomas Electronics	Glass Funnel	1 ea.	Glaswerk Wertheim (FRG)
CRT of DU	Thomas Electronics	Glass Faceplate	1 ea.	Glaswerk Wertheim
CRT of DU	Smiths	CRT	1 ea.	Mitsubishi

The determination of system parts for the P-7 cockpit display is not mature enough for further analysis at this time. However, the data obtained is sufficient to indicate that the displays will use some critical foreign sourcing. The mission (back) end of the P-7 aircraft contains most of the avionics that are also used in the P-3C Update IV. This includes five 19-inch color displays (CDs) furnished by Smiths Industries (U.K.) using Mitsubishi (Japan) CRTs and five flat panel 18 inch x 5.5 inch AC plasma displays (programmable electro plasma entry panel).

The P-7 development experience shows that CRT technology is not yet fully developed and a CRT marketplace will exist in the future. The P-7 program also indicates that dealing with foreign suppliers presents cost and schedule problems for U.S. systems integrators (e.g., Astronautics' experience with Ferranti and Sony).

4. Other Aircraft Programs

a. ATF/F-16

General Electric was the original developer of the flat panel liquid crystal display (LCD) for these aircraft. Subsequently, the technology and manufacturing rights have moved through Thomson CSF (France) and now are owned by Sextant (France). Negotiations are under way for Sextant to supply the panels to Kaiser, the U.S. integrator.

b. A-12

Ovonic Imaging Systems is the manufacturer for what should be the first military use of large (greater than 5 inch by 5 inch) flat panel LCDs. Two of the displays measure 8 inches by 8 inches, while six others are 6-by-6 inch squares.⁵ Ovonic reportedly uses diode switching rather than the commonly used thin film transistor switching for the LCD display.

c. F-15

Honeywell is building a 5 inch by 5 inch color CRT using a Matsushita cathode-ray tube. The USAF has provided \$2M to Tektronix to build a U.S. version that also has some technical improvements. Foreign sourcing of the fiber and coil is the same as noted for the F/A-18 MPCD.

d. C-130J

Lockheed has announced a potential upgrade of C-130s incorporating new technology and reducing life cycle costs. The new C-130J would have a two-person cockpit with four liquid crystal head-down displays and two head-up displays. The proposed flat panel displays will be NVG compatible.⁶

5. Production Manufacturing Equipment

Several display manufacturers have noted that many of the production machines at their vendors' plants come from Japan and Germany. In addition, during visits to several system manufacturers, foreign-made production equipment was noted. Complete production equipment inventories are to be supplied by Litton-Canada. The factory test

⁵ *Aviation Week and Space Technology*, 26 June 1989, p. 75.

⁶ *Aviation Week and Space Technology*, 27 November, 1989, pp. 45-49.

equipment, intermediate and operational test equipment for the F/A-18 and AV-8B MPCD were all built with commercially available U.S. parts, some of which contain foreign electronics (e.g., Hewlett Packard computers). P-7 production equipment is not yet specified. More time is needed for further analyses and conclusions.

6. U.S. and European Manufacturers

The principal manufacturers of cockpit displays are Kaiser, Astronautics, Smiths (U.K./U.S.), GEC (U.K.), Allied Signal (former Bendix), Honeywell, Collins, Loral, Thompson CSF (France), Sextant Aerospatiale (France), AEG (FRG), Plessey (U.K.), Litton, and Westinghouse. Some of these companies manufacture entire systems while others make major components. Generally speaking, the manufacturers that are doing business with the DoD are required to have two sources for their components. Economics and delivery requirements dictate which vendor gets the order for the bulk of the quantities required. Honeywell (formerly Sperry), Rockwell-Collins, and Thomson CSF seem to dominate the commercial airline display market.

7. Japanese Manufacturers

An example of the Ministry of International Trade and Industry (MITI) technology leadership is the creation of a Japanese consortium to develop and produce a 1-meter-square active-matrix liquid crystal display (LCD). The lack of U.S. government or industry leadership, along with active Japanese investment policy, are resulting in a rapid Japanese rise to dominance in manufacturing CRT and flat panel equipment and are further eroding any U.S. capability. Other indications of Japan's efforts to become dominant in display technology include the following:

- FLOROD in Gardena, CA, currently makes a very good laser repair station using a xenon laser. The device has an extremely accurate capability of doing online microcircuit repairs. They are shipping two per month to Japan. This rate is of concern and could be an indicator of Japanese intent to dominate flat panel manufacturing. Florod has noted that their machines are being used in multiple-circuit thin film transistor LCD manufacturing to improve the LCD yield.
- Giant Technology Corporation is made up of Asahi Glass Co., Casio Computer Co., Hitachi Ltd., NEC Corporation, Sanyo Electric Co., Seiko-

Epson Co., and Sharp Corporation.⁷ The Corporation is developing polycrystalline silicon driver circuits with horizontal operating rates of 100 kHz and vertical rates of 10 MHz. There needs to exist a good consumer market for displays to attract venture capital. Japan is vertically organized to take advantage of the range of consumer products. Japan also has economic reason for technology and manufacturing miniaturization.

- The best production stepper lithography machines are made in Japan by Canon and Nikon. This technology is one of the base technologies for flat panel manufacturing.
- Japan seems to be becoming dominant in the thin film transistor (TFT) liquid crystal display (LCD) technology and manufacturing. This may be an indicator of the real problem in the future relative to foreign dominance in displays.

8. Opinions of Display Experts on Dependence

The Society of Information Displays (SID) is the common forum for display research and development. This international organization has about 3,000 members with several chapters, including a very active chapter in Japan. SID sponsors several trade fairs during the year, at which technical papers are presented and subsequently published in a monthly journal. According to members of SID, including the current chairman, originators of technical papers published over the past 5 years are dominantly Japanese. Several U.S. display experts have recently expressed the opinion that Japan is conducting the best display research.

Mr. Tannas, the chairman of the SID, stated that the U.S. is becoming weaker on a daily basis in displays, while Japan will gradually dominate the market. His reasoning is:

- U.S. companies are unwilling to invest in both "risky" developments and long-term manufacturing equipment.
- There is no concerted U.S. industry leadership.
- Japan is vertically organized and uses displays in consumer products. Although many of these products have individual low profit margins, when viewed from a total market, there is a profit to be earned.

⁷ For more information on Giant Technology Corporation, see "Defense Department, Japan in Negotiations for Flat-Panel Displays," *New Technology Week*, 20 November, 1989. Also see *Japanese Developments in High Definition Television*, by Tech Search International, Austin, Texas, September, 1989.

- Japan has a national strategic plan, administered by MITI, and the display business, inter alia, has been parceled out to avoid duplication of development and manufacturing effort.

Mr. Gene Adam of McDonnell Douglas observed that Japan is committed to spend whatever it takes to obtain world market share in information and entertainment displays. He noted that Japan is developing 15-foot-square displays for billboards and theaters.

B. INFLUENCE OF DEFENSE LAWS, POLICIES, PROGRAMS, AND FINANCIAL PRACTICES

1. Overall Policy Guidance

a. Waivers

All of the manufacturers and vendors contacted were aware of the "Buy America Act" but the basic problem they were trying to solve was one of cost and schedule. In the case of foreign manufacturers, such as the Smiths HUD and the Smiths MPCD, there are waivers granted for the entire display.

b. Nonstandard Parts (NSP)

Initial program requirements that for DoD products contractors must submit nonstandard parts to the government for approval has been well understood and accepted. However, subsequent requirements for "second" sources for vendor parts is an increasing problem whenever quantities required for follow-on buys and spare parts are so low as to be uneconomical (from the manufacturer's point of view).

The DoD system is not uniform, but generally the NSP listings are sent to the Defense Electronic Supply Center (DESC), where an initial advisement is made for a substitute or approval. The Naval Avionics Center (NAC) has a parallel process that further refines the NSP approval cycle to avoid proliferation of parts. In either case, the contract could be for contractor-furnished equipment (CFE) or a government-furnished equipment (GFE). The key point is that NAC provides a NSP technical input at the R&D level (while the item is being developed) and not at a point so late in the life cycle that the part has been selected and any delay in approving the item will impact delivery. Studies have proven that this early attention produces long-term logistic savings. A further improvement of the NAC process, being initiated for the A-12 aircraft, permits subcontractors to send direct submissions to NAC. The cycle is shown in Fig. B-I-4.

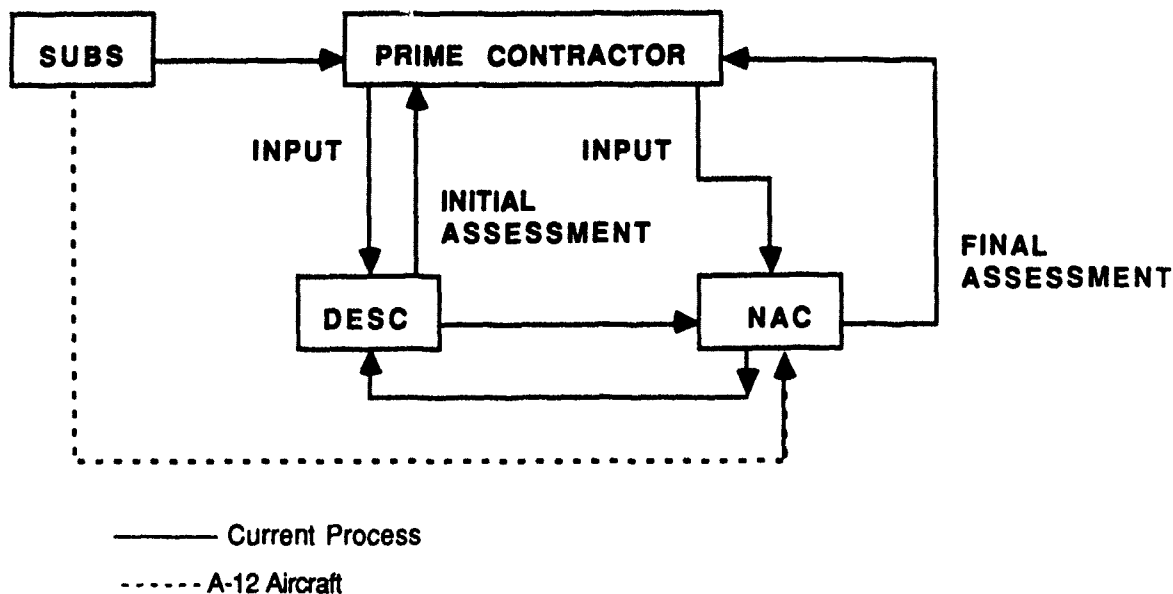


Figure B-I-4. Nonstandard Parts Approval Cycle, Naval Avionics.

MIL-E-5400 requires second-source approval, but *who* approves is not specified. Therefore, companies have resorted to getting local DCAS approval or have let the approval process slide toward infinity. There do not appear to be any checks and balances for second sources. Monitoring further deteriorates if the initial source goes out of business; then activation of the second source and the approval can be done by the contractors or the government. In either case, our research uncovered no foreign parts approval guidance.

In contrast to the general situation, NAC has an effective parts control process under way, and its database can now disclose all foreign parts approvals after 1985. A computer run was furnished to IDA to permit verification of this statement by NAC personnel. The data provided a good example of the depth to which one needs to search to find the original source of the parts. Table B-I-7 provides an example of a "food chain" for a particular part. Even though this foreign parts monitoring capability exists at NAC, there appears to be no policy to use the data to monitor or implement any foreign sourcing guidance or limitations.

2. DoD Requirements

a. Competition

Competition between Kaiser and Litton as primes for the HUD, MDI, and MDRI appears to be working as intended. Kaiser essentially is responsible for parts control, to

assure commonality of parts, subassembly, and assembly between the two manufacturers. Two vendors likewise provide the CRT for the MDRI.

Table B-I-7. Multipurpose Color Display Typical "Food Chain"

Corporation	Product
McDonnell Douglas	F/A-18 Aircraft
Smiths	Multipurpose Color Display
Textronics	Cathode-Ray Tube
WAMCO	Vendor
WAKOH (JA)	Filter Manufacturer
? (JA)	Proprietary Material for Filter

b. Data Rights

Intellectual property (data) rights have become a point of contention between contractors and DoD since advocacy of competition and dual-sourcing policies was initiated in earnest. All of the companies contacted had concerns. One result of these DoD policies is the loss of incentive to do business with the government, particularly in research and development, when the government does not allow proprietary rights. Some manufacturers asserted that their competitive edge disappears when the government appropriates their data package and runs a competition against them without an adequate study of the market needs and economies of scale. When order quantities are split among vendors, the cost of capital equipment for each has to be amortized across a smaller quantity and most likely a shorter time period.

c. Military Specifications & Standards

There was no consensus among those contacted in the course of the study as to whether or not military part specifications and standards exceeded what is justified by the conditions of use.

3. DoD and SPO Programs and Practices

a. DoD Support

Display suppliers assert that partly because of lack of U.S. government support for *primary display manufacturers*, the manufacturing of displays is moving offshore. Instead,

they say, DoD development money is going to technology development organizations. As the next section suggests, support might be better targeted.

b. R&D Versus Production

Japanese, Israeli, and French companies proceed to develop and produce new display technology because of an abundance of government support money. Foreign government support for R&D helps these companies with several generations of technology development, while at the same time shielding them from competitive pressures faced by U.S. companies. Automated equipment has recently been seen at Thomson CSF in great quantities. The Kaiser people noted that their own firm is a *product development* corporation. The U.S. government is perceived as providing *direct* R&D money for displays mainly to small companies, laboratories, and universities. Yet only large companies have corporate funding available to establish and retain a production base, and thus a gap exists between production and R&D funding.

Kaiser has received no funds *directly* from DoD to develop displays but does receive some R&D funding from prime contractors. Because this money first passes through the prime contractors, total budgeted funding for displays is diluted by the time it reaches the display or component manufacturer. This situation results from a general trend in the U.S. in which federally funded research and development for defense is now over 90 percent product related. In Japan, roughly two-thirds of total R&D money (government and private) is devoted to the manufacturing/production process. The focus in Japan is on producing high-quality products cheaply and obtaining the broadest market share possible with those products. Clearly, there is a wide gap between product and process in the U.S.⁸

There are several possible explanations for this situation. One is the lack of industry and government agreement concerning the need to emphasize manufacturing processes in R&D funding. Another apparent cause is a political orientation which considers that long-term benefits of improving manufacturing processes should be the responsibility of the private sector. A good example of current defects in the link between development of a model and production of the end item is the Sarnoff Laboratory program. Although Sarnoff has been doing significant development work and attempting to

⁸ This point has been noted in the DoD's Manufacturing Technology (MANTECH) Program, and was reiterated at the Defense Manufacturing Board's 17 October Meeting, Washington, D.C.

commercialize this work, its success thus far has been very limited. An opinion offered by Astronautics personnel was that "there is no U.S. leadership in the government or industry for displays." Further comment by Astronautics personnel indicated that NASA requirements in displays are governed only by economy and availability.

Another illustration of shortcomings in the interplay between DoD R&D and procurement policies and market supply responses is a Tektronix company policy prohibiting involvement with the government in flat panel displays. The company has cited a lack of return on investment as a key factor in this decision.

c. Congressional Requirements

From discussions with Kaiser personnel it was evident that they were frustrated by the combination of Congressional requirements for sourcing competition together with initiatives that result from the Nunn amendment and the use of foreign technology developments. "Nunn monies"⁹ reportedly "force" companies like Kaiser to seek cooperative R&D abroad. This usually involves high-tech R&D, with uncertain applications, which Kaiser would not otherwise fund. In an international joint venture, a smaller company like Kaiser will not retain control over the direction of R&D. Therefore, in this instance, a U.S. defense manufacturer in a critical market sector invests with no guarantee that the R&D venture will satisfy their future needs. Requirements for joint R&D often put smaller companies like Kaiser at a competitive disadvantage internationally because they lose control of limited R&D resources.

d. U.S. Export Controls

U.S. export restrictions on third-generation NVG helmets were cited by one display supplier as having the result of encouraging France to become dominant in the European market. In essence, U.S.-owned subsidiaries of GEC and Smiths are viewed by their U.S. competitors as additional leverage for GEC (U.K.) and Smiths (U.K.) to outcompete other U.S. manufacturers using U.S. government regulations for their own benefit. U.S. export restrictions allow these European-owned companies unrestricted access to export markets, while not preventing them from competing in the U.S. defense market--the only market remaining for U.S. suppliers.

⁹ See NATO Cooperative R&D Amendment, *Congressional Record*, 22 May 1985, PS 6756.

e. Offsets

Mr. Paul Schlegel, of NAVAIR's F/A-18 Program Office noted that he has been seeing foreign-sourcing "creep," caused by offsets agreements--a growing problem in the aircraft industry. In particular, the F/A-18 program office, in negotiations with Canada, Australia, Kuwait, Spain, Switzerland, France, et al., finds it increasingly difficult to satisfy all the foreign requirements for sourcing from these countries as a condition of their F/A-18 purchases.

4. Financial Developments

a. Mergers and Acquisitions

In the course of this study, several display experts in the government and industry noted that General Electric had been funded by the DoD over a long period of time and had been considered a leader in the thin film transistor liquid crystal display (LCD) field. Unfortunately for the U.S., General Electric decided to sell this technology and its manufacturing rights to Thomson CSF (France). GE did not foresee a near-term return on the capital equipment investment that would warrant it to "commercialize" development efforts. In a quick turnabout, Thomson CSF has spun off its own avionics division and that division has been merged with three former divisions of Aerospatiale. The resulting new French Company, Sextant Avionique, now owns the original General Electric display technology and production rights. Another European initiative involves Thompson CSF funding of "Euro Display," which is a joint venture of Sextant (France), Kaiser (U.S.), and VDO (FRG). These companies may possibly combine to manufacture a standard display. The display could then be integrated by Kaiser for U.S. military needs. This General Electric experience indicates that the ownership of technology and production capability is fluid and easily changeable.

Another relevant acquisition of a company in the display business was the purchase of Panelvision of Pittsburgh, PA, by Litton-Canada. Panelvision technology, plant equipment, and some personnel have been transitioned to Toronto. Litton-Canada has maintained this technology but is negotiating with a Japanese firm to provide backup panels if their design does not prove to be economically viable.

C. TRENDS IN DISPLAY TECHNOLOGY

1. Monochrome Versus Color Displays

There is general agreement that the U.S. manufacturers have been generally strong in monochrome but weak in color CRT display technology. However, both civilian and military market demand has shifted toward color displays. No definitive study has proven that color provides any advantage over monochrome displays (except for map displays), but the trend toward full color has great momentum. A challenge remains to solve the human interface problem that occurs because of disparities in individuals' vision, particularly involving variation in color perception. A possible solution is to "personalize" the display using a personal computer chip that will "normalize" the display for individual users by compensating for disparities.

2. CRT Technology Improvements

CRT display technology is not static. Color-beam indexing technology was originally developed from U.S. patents by Japanese companies (most notably Sony), Ferranti, and Telefunken for projecting improved-brightness TV. Beam indexing does not currently have resolution comparable to a shadow mask. However, the alternative shadow mask technique reportedly has vibration problems, creates more heat (infrared), and also has a lower brightness characteristic.

Beam indexing (Trinitron) uses color strips and not conventional dots to obtain brighter color displays. (See discussion of P-7 aircraft.) Beam indexing reduces problems associated with environmental magnetics, an ongoing problem for display installations. Another unrelated CRT improvement is the development of low-power CRT drive circuits that require no forced cooling air.

3. Limitations of CRT Improvements

Despite significant development, CRT displays have a basic size limitation that it is not economical or technically desirable to exceed. Projection-type CRTs have been developed to expand the viewing screen to movie theater dimensions. However, basic expansion of the display in this manner has other limitations, particularly in aircraft design. The power applied to a CRT for operation and the inherent cooling requirements needed for reliable operation of the electronics therein have been a critical problem that is sometimes only solved by using refrigerated air during operation. On average, CRTs use about

10 times more power than a liquid crystal flat panel display. The aircraft manufacturers are required to dissipate the heat *and* suffer the consequences of lower avionics reliability due to the high junction temperature failures of the entire avionics suite. The space behind the cockpit panel is costly "real estate," and CRTs sometimes extend up to 18 inches in depth. In addition to this problem, the electromagnetic output of the device must also be controlled by proper design and placement.¹⁰

4 . Flat Panel Displays

The need exists for a uniform type of display that can be large without introducing distortion and viewing angle problems. The military has need for large (4 ft × 4 ft) panels for command and control. Smaller panels (12 inches × 12 inches, or covering the entire cockpit) have potentially broad applications in aircraft, ships, and tanks.¹¹

Flat panel technology has been evolving over the past 30 years in the laboratory. Only within the last 5 years, however, have companies manufactured flat panel displays in any quantity. However, the first large (greater than 5 inch by 5 inch) flat panel has not yet flown in a production aircraft. The A-12 will probably be the first to incorporate flat panel technology.¹²

Flat panel displays can be divided into two general types: passive and active.¹³ Passive displays use liquid crystal technology and require some form of backlighting; thus reflected ambient light is needed for visibility. This technology provides better resolution in direct sunlight and is considered by many to be the least expensive of all flat panel choices. There are two subcircuit technologies in LCDs: thin film transistors (TFT) and metal-insulator-metal (MIM) diodes. The TFT design tends to dictate the size of the pixel and thus the spacing of the rows and columns for the display. A major obstacle which remains is to define the resolution over a large display. The alternative is to use MIM diodes to control the circuit of each pixel. In either case, the LCD flat panel may use back-

¹⁰ *Electronic Display*, p. 212.

¹¹ *Jane's Avionics*, 1987/8, p. 409.

¹² *Business & Commercial Aviation* reports in its October 1989 issue (Vol. 65, Issue 5, p. 32) that "Yokogawa Electric (Japan) is said to be working on a liquid-crystal 'flat-panel' instrument display for light piston single and twin aircraft. In ground trials of the first screen, a multifunction screen reportedly supplied navigation and flight performance information. Flight trials will get underway in 1990."

¹³ *EDN*, September 4, 1986, p. 79.

lighting from another source, such as fluorescent, to improve the contrast ratio. TFT LCD technology currently holds the most promise for sufficient resolution in an aircraft cockpit.

Active flat panel displays that generate their own light include the following types:

- Gas discharge
- AC plasma
- DC plasma
- Electroluminescent (EL)
- Vacuum-fluorescent.

Using EL technology, there is a potential for 2000-line displays. There are good red and green phosphors. Better blue phosphor is needed to make a good white when all the colors are combined. Most designs give up more than 67 percent of available light to get good color; thus no satisfactory color EL display has been developed.

A technical limitation with all flat panel displays is addressing the individual pixels in the panel. In instances when color is required in the display, LCDs will eventually provide the best resolution. In LCD technology some designs have the pixel with subelements of three colors in a quad structure, because there is no easy way to stack the thin film material. The resulting quad can use two green subelements in order to get good white when all the colors are mixed. An alternative approach is to have a white subelement to get better luminescence. This subelement design, however, complicates the drive circuit by a factor of four.

red	green
green	blue

Amorphous silicon has the lowest conductivity of possible LCD materials. A potential advantage of polycrystalline silicon is that the driver circuits can be incorporated into the display design and reduce the external wires by an order of magnitude. Although the GE (now Sextant) design uses amorphous silicate and needs a refresh rate of 115 Hz, the Litton process uses cadmium selenide and only needs to refresh at 30 Hz. Separation of the matrix remains a problem, but not the reliability of the thin film transistors. The separation needed is between 2000 and 5000 angstroms and the process relies on high-quality, leakproof oxides to keep the X and Y circuits apart. Automatic testing devices are needed to determine acceptable resistance values. Table B-I-8 lists North American LCD manufacturers.

Fiber optics are particularly applicable to large screen displays. One application is based on a precisely configured matrix of fiber optics as pixels that transmit images produced by a variety of light sources. Fiber optic transmission between the sensors/ computers and the display is another technology application.

Table B-I-8. North American LCD Manufacturers

Company	Status
Alpha Sel	Out of business when Honeywell venture capital was not provided.
General Electric	Technology and manufacturing rights sold to Sextant (FR) via Thomson CSF.
Sarnoff Laboratory	Good R&D--no production experience.
Litton-Canada	Good R&D--production capitalization has been found--absorbed Panelvision.
Ovionics	Good R&D--financially strong--production experience.
Infocus	Patents applied for.
Xerox/Raychem	Uses thin film transistors.

Clearly, the commercial manufacturing base for flat panel LCDs is limited. This is not the case in other countries, particularly Japan, where many companies are developing large flat panel displays for both military and commercial use.¹⁴ In the area of flat panel displays, advanced manufacturing capability is located almost exclusively offshore.

¹⁴ Refer to footnotes 6 and 11.

III. CONCLUSIONS AND RECOMMENDATIONS

A. SOURCING POLICIES

This study concludes that certain critical display technologies and components are only available from foreign sources. If the availability of key components and technologies is deemed critical to national security, procurement from onshore sources may eliminate some national security concerns. This is particularly important for critical CRT components, such as optical filters and molded ferrite deflection coils. But it is important first to determine if it is economical to establish U.S. sources for these items. Each procurement program is different, so there is no standard formula for ensuring onshore acquisition. However, in programs which involve technologies which are deemed critical, program managers should ensure a manufacturing source in the U.S.

- USD(A) should take action to ensure U.S. manufacture of such items. For long-term production runs, USD(A) should develop a system to assess the feasibility of a second-source approval cycle for CRT components and parts, so that a domestic source is developed for those otherwise available only offshore.

B. DOD ACQUISITION REQUIREMENTS, PRACTICES, AND PROGRAMS

There is no comprehensive, up-to-date database which allows DoD to determine whether a company is U.S.-owned or owned by a foreign parent. Nor is there a commercial way for DoD agencies to obtain that information easily. Procurement programs need information regarding which U.S. firms are in certain markets, and which foreign firms produce high-quality components. It is also important that U.S. R&D money be used to assist U.S. firms. Improved information is necessary for this to happen.

- DARPA and USD(A) should jointly develop a database containing information regarding defense contractor ownership and types of components produced.
- USD(A) should establish DoD-wide requirements to determine which firms are sole sources for critical items and to determine levels of foreign sourcing, so that no situations develop leaving the U.S. vulnerable to an unreliable supplier. This database should then be expanded to include components supplied to

prime DoD contractors, so that the primes are aware of where critical components are produced. A further extension would include basic material sourcing and production equipment used to manufacture critical parts.

- The process of obtaining a manufacturer's code should be further refined so that it can be used in the future to determine foreign sourcing information.
- A process of collecting data on nonstandard parts, similar to that at the Naval Avionics Center, should be expanded throughout DoD. In this manner data on foreign sourcing can be automatically gathered so that the extent of foreign sourcing is constantly accessible.

C. R&D IMPLICATIONS

Flat panel information displays are likely to be of critical importance to the DoD as aircraft and other systems become more display dependant. While in Europe and Asia the technology will be driven by commercial applications, in the U.S. the driver initially will be military systems. Eventually, commercial and military applications must move closer together in the U.S. The military display market is not large enough to promote a thriving U.S. display industry.

- DARPA and the Department of Commerce should establish standard sizes and electronic interfaces, allowing manufacturers to prepare for future markets. This will help create a vertical market in the U.S. and encourage development in the U.S. of advanced display technology.
- DARPA should ensure adequate manufacturing capability in future R&D contracts. There is no need to invent a better product if assets cannot become available for producing the item.
- DARPA should continue to provide funding for R&D in CRT technology, as the widespread use of flat panel technology is several years in the offing.

D. RESPONDING TO SOURCING TRENDS

The DoD has a responsibility to its producers to become a better customer. This entails helping to establish a better marketplace for DoD suppliers, including lower tier firms.

- DoD, specifically DARPA and USD(A), should encourage tax incentives for long-term investment by U.S. corporations in capital equipment to manufacture flat panel technology.
- USD(A) should consider the dependence solution used in the ball-bearing industry. If it is important to keep display technology on shore, establish a

DoD procurement regulation that would require the use of only a U.S.-manufactured display with U.S.-manufactured parts, unless a waiver were granted for specific reasons (quality, offset, etc.).

E. AREAS OF FURTHER STUDY

- Investigate manufacturing equipment dependence for CRT and flat panel technologies.
- Expand aircraft display analysis to other platform users of displays such as ships, command and control centers, and tanks.
- Assess the DoD needs for displays for long-term information and training requirements.
- Further investigate source requirements within NASA and other non-DoD contracts.
- Determine the relative health of U.S. display manufacturers compared to manufacturers in European and Pacific Rim countries.

APPENDIX B, ANNEX II

APG-66 & APG-68 AIRCRAFT RADARS

Herbert R. Brown

Peter B. Almquist

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EXECUTIVE SUMMARY

The objective of this system study is to identify and analyze the sourcing of specific microelectronic (discrete and microcircuit) devices used in the Air Force F-16 radars. The analysis is to determine the extent of foreign sourcing of components, parts, and materials as well as foreign processing, packaging and assembly of these devices, and the related foreign technologies. This analysis is part of a more extensive study for DARPA to determine the extent, nature, and trends in dependence on foreign technologies in selected Defense systems.

Three versions of the F-16 radar (the AN/APG-66, the AN/APG-68, and the AN/APG-68 with advanced programmable signal processor) were selected because they represent state-of-the-art radar systems and have the potential of illustrating foreign sourcing trends.

Manufacturers for approximately three-quarters of the microelectronic device *configurations* used in the three radar versions were identified. Site visits and interviews were then conducted at the principal manufacturers of these radar parts, representing approximately one-third of the total parts types used in the three radar systems.

The study identified (1) growing foreign sourcing trends both in wafer fabrication and in packaging and assembly processes, and (2) defense policies, procedures, and financial factors that influence foreign sourcing.

A. FINDINGS

1. Foreign Sourcing

- All of the individual microelectronic circuits (or dice) used in the semiconductor integrated circuits (IC) and discrete devices evaluated in this study were fabricated at U.S. onshore companies.
- Most of the U.S. wafer fabrication facilities rely on foreign-owned sources of silicon; however, most other materials needed in the fabrication process were generally available onshore.

- The microelectronic devices evaluated in this study were found to be almost totally dependent on foreign sources for packaging material.
- All microelectronics manufacturers visited indicated a high reliance on Japan-sourced lithography equipment, a critical portion of the fabrication process. However, all other types of wafer fabrication equipment appears to be available from onshore sources.
- The vast majority of the F-16 source control drawing (SCD) part types evaluated during this study (67.9 percent) were packaged and assembled offshore. The total number of offshore-assembled part types represented approximately 29 percent of the F-16 microelectronic device types evaluated.

Beyond the specific device-related findings on foreign sourcing, study findings included an array of business environment factors that affect the availability and competitiveness of onshore sources and account for the trend of decline in onshore sourcing:

- Three specific factors (quality assurance cost burdens, DoD cost-accounting standards, and offshore labor rates) create an environment in which (1) it has become extremely difficult for onshore microelectronics manufacturers to compete with offshore sources, and (2) DoD prime weapon system contractors must look to offshore microelectronics manufacturers to keep costs low.
- The skills and knowledge (technology) necessary to produce high-quality devices are moving offshore because of the massive microelectronic device quantities being produced offshore.
- No stable process or means exists to assure a continuous source of critical R&D resources at microelectronics component and equipment supplier levels.

2. Influence of Policies and Practices

- The parts selection trends for the evolving F-16 radars have been moving away from the MILSPEC (Mil-M-38510 and Mil-S-19500) type devices to MIL-STD-883 screened (SCD) devices that predominantly rely on offshore sources for assembly, and to a lesser extent for offshore wafer fabrication.
- IC manufacturers agree that the DoD initiative to streamline the quality assurance certification processes [Qualified Manufacturers List (QML) concept] will reduce costs; however, if offshore sources are allowed to participate, any incentive to use domestically fabricated parts will be lost and DoD's reliance on offshore microelectronics sources will increase markedly.

- Current DoD cost accounting practices raise parts cost and make parts from onshore facilities less competitive.
- Trade restrictions may inhibit the use and development of new technologies.

B. RECOMMENDATIONS

The study team concludes, on the basis of the radar systems studied, that (1) there is substantial use of foreign sources for microelectronics assembly, packaging materials, assembly equipment, and lithography equipment; (2) if DoD desires to reduce system reliance on this foreign sourcing, there is no single solution that will bring these reductions about; and (3) a comprehensive approach is required to reduce the existing forces tending to increase offshore ascendancy in these aspects of microelectronics technology. The following recommendations are made:

- The Under Secretary of Defense for Acquisition should direct the armed services to enforce existing policies that establish the order of precedence for microelectronic component selection in DoD weapon systems.
- The Defense Acquisition Regulation Council should give greater priority to efforts to develop and implement a solution for the burdensome cost accounting practices imposed on microelectronics.
- The Under Secretary of Defense for Acquisition should direct the Defense Electronic Supply Center (DESC) to restrict the new proposed quality assurance concept (QML) to onshore sources.
- The Under Secretary of Defense for Acquisition should initiate a series of microelectronics technology packaging and assembly studies. These studies and research efforts should specifically address new materials and processes that are applicable to DoD high-quality/reliability requirements and also lend themselves to high-volume competitive production manufacturing processes.
- DARPA should investigate opportunities to develop a Government policy as well as a process that funds R&D for critical technology areas that are becoming dependent on foreign sources.
- DARPA should fund a program in advanced microelectronic lithography that supports development of domestic technology for the range of lithographic processes needed for defense applications in the 0.5 μ to 0.25 μ feature sizes.

I. INTRODUCTION

A. STATEMENT OF THE PROBLEM AND FOCUS OF THE STUDY

1. Problem

There is a growing perception within DoD and the defense industries that U.S. weapon systems are becoming dependent on foreign sources for state-of-the-art technologies. To examine this broad perception of growing technology dependence, DARPA tasked IDA to conduct a study of selected defense systems (or subsystems) and determine the extent, nature, and trends in the use of, and dependence on, foreign technologies. This portion of the study addresses the radar subsystems on the United States Air Force F-16 aircraft.

2. Focus of the Study

The AN/APG-66 and AN/APG-68 radars, currently in use in the F-16A/B and F-16C/D aircraft respectively, were selected for analyses. These radars were selected because they represent (1) widely used state-of-the-art operational radar systems and (2) a linear progression in technology from the AN/APG-66 to the newer AN/APG-68, making it possible to illustrate any trends in dependence as radar systems have evolved.

To stay within given schedule constraints, the F-16 radar study scope was narrowed specifically to semiconductor discrete and microcircuit device technologies. The study objective was to identify specific microelectronic devices used in F-16 radar and to analyze their dependence on foreign-sourced components, parts, materials, and equipment, as well as foreign processing, packaging, assembly, and associated foreign technologies.

3. Description of Radars

Both F-16 radars are coherent, multimode sensors, designed to provide all-weather air-to-air and air-to-surface fire control radar (FCR) capabilities. They were designed, developed, and produced by Westinghouse. At present there are three versions of the

radars in use and/or production for the United States Air Force: the AN/APG-66, the AN/APG-68, and AN/APG-68 with advanced programmable signal processor (APSP).

The AN/APG-66 radar consists of seven line-replaceable units (LRU): antenna, low-power radiofrequency (RF) unit, transmitter, digital signal processor, radar computer, radar control panel, and rack. The AN/APG-68 FCR is an upgrade of the AN/APG-66 and provides the F-16 with improved range for detection of airborne targets, as well as additional modes and submodes of operation in both the air combat and all-weather ground attack missions. The AN/APG-68 (Fig. B-II-1) replaced five of the AN/APG-66 LRUs (low-power RF, transmitter, digital signal processor, radar computer, and radar control panel) with three new LRUs (modular low-power RF, dual-mode transmitter, and programmable signal processor). The most recent improvement to the F-16 radar is the APSP. The first production deliveries including the APSP are projected for 1991. The APSP is a replacement for the original programmable signal processor LRU in the AN/APG-68 and uses more advanced microelectronics technology to improve the operational characteristics of the radar while at the same time improving its reliability and maintainability. This change has been approved by the F-16 System Program Office and will be incorporated in future production versions.

B. STUDY APPROACH

The initial step in this study was to identify the semiconductor discrete and microcircuit (herein referred to as microelectronic) devices in the AN/APG-66, the AN/APG-68, and the AN/APG-68 with APSP. From this list of microelectronic devices, vendors with specific products that qualified to meet the requirements of the Westinghouse SCDs or of the applicable Military Specifications were identified. Interviews with selected manufacturers of microelectronic devices were conducted to assess the level and extent of reliance on foreign sources of materials, equipment, labor, and/or facilities.

1. Identification of Microelectronic Device Vendors

The microelectronic devices in this study fall into two categories: semiconductor discretes and microcircuits. Semiconductor discretes are single-function semiconductor elements (e.g., diodes, transistors) packaged as individual devices. Microcircuits are multiple semiconductor elements combined monolithically in an *IC* or multiple components (including semiconductor elements, ICs, and resistors) combined in a *hybrid* package.

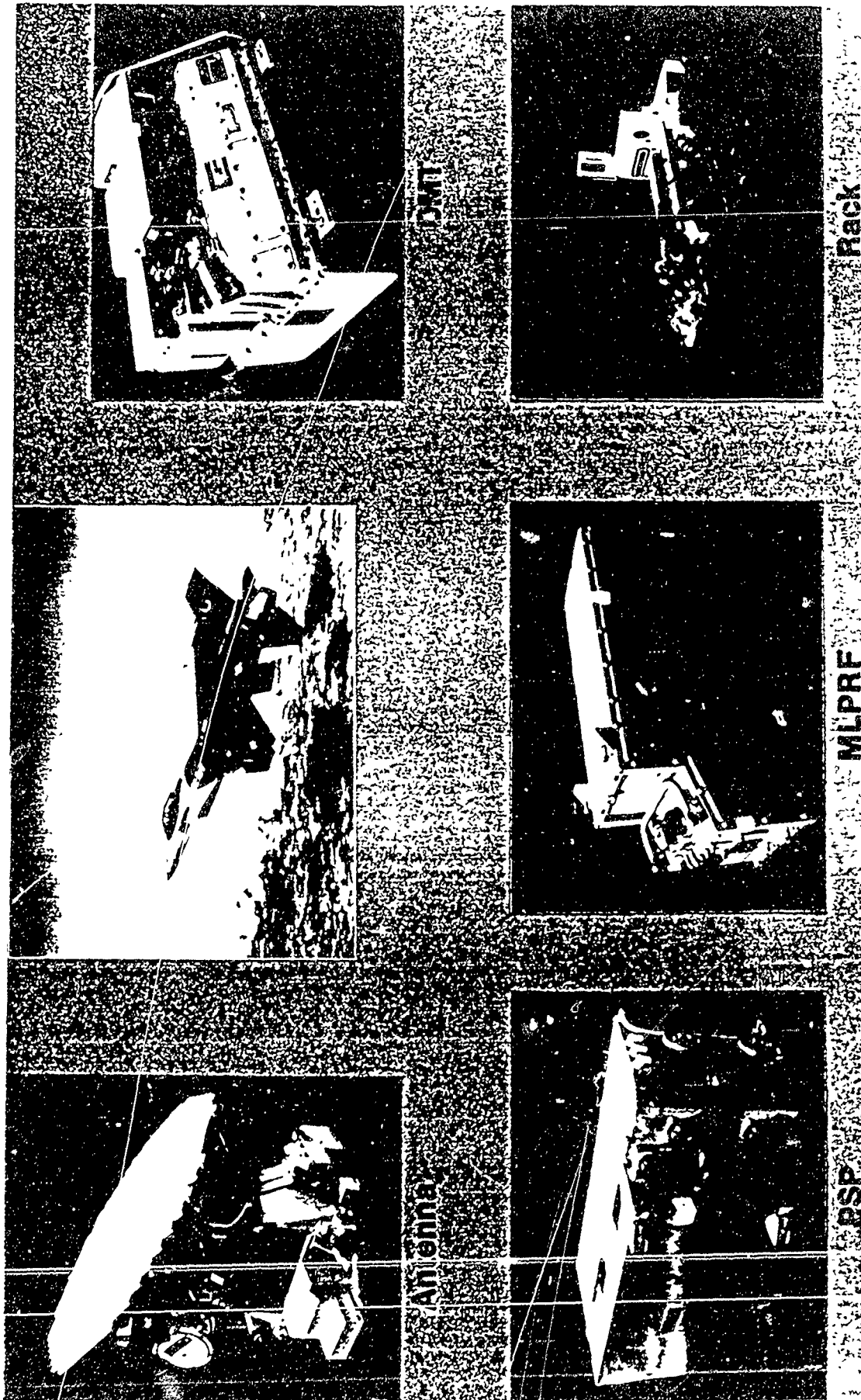


Figure B-II-1. AN/APG-68 F-16 Radar.

A wafer is the result of a complex fabrication process of creating on a semiconducting material substrate (usually silicon) multiple copies of the desired semiconductor circuit. The individual semiconductor dice or "chips" are then cut from this processed wafer.

The microelectronic devices in the AN/APG-66 and AN/APG-68 radars were identified from computer listings of the complete radar assemblies and components actually used in the latest production versions. These lists are generated quarterly by the radar prime contractor (Westinghouse) and retained by the Ogden Air Logistics Center, Hill Air Force Base, the cognizant logistic agent for this radar. Many of these microelectronic parts are common to both of these radar configurations.

Westinghouse also provided the study team with a listing of microelectronic devices new to the APSP modification to the AN/APG-68 radar. Although the parts list for the AN/APG-68 radar with the APSP modification includes many devices found in the AN/APG-68 radar, the information provided by Westinghouse reflects only those devices that are unique to the APSP modification.

Manufacturers for the specific microelectronic devices used in the fabrication of the F-16 radars were identified through three sources: (1) Westinghouse SCDs retained at Hill Air Force Base, (2) the Qualified Products Lists (QPL) for discrete devices (QPL-19500-110, 20 July 1989) and microcircuits (QPL-38510-79, 14 July 1989), and (3) interviews with Westinghouse personnel.

2. Limitations of Data Sample Size

The IDA study team identified 957 unique microelectronic device configurations being used in the various Air Force F-16 radars (Table B-II-1). In this context, a device configuration is a specific part that is qualified against the Westinghouse parts lists for the respective radar. There may be only one or many of any one configuration in the radar. While time constraints may have led to the omission of a few microelectronic devices, the study team estimates that the number of device configurations identified exceeds 95 percent of the total number used in the three radar configurations.

In the limited time available, the study team identified vendors for approximately three-quarters of these microelectronics device configurations. Almost 100 manufacturers were identified as qualified sources for this subset of parts (those either in actual use or eligible as a spare part). There was no attempt to focus on any specific device type or class, and the collection of the data relative to the specific vendor sources was most

influenced by the immediate availability of Government-maintained drawings for manual viewing at Hill Air Force Base.

Table B-II-1. F-16 Radar Part Types Identified

Type	APG-66	APG-68	Unique to APG-66	Unique to APG-68	Totals
MIL-S-19500	86	98	68	0	154
MIL-M-38510	101	132	89	45	235
883-Screen* (SCDs and SMDs)	237	313	255	76	568
TOTALS	424	543	412	121	957
JAN-Certified**	44.1%	42.4%	38.1%	37.2%	40.6%
883-Screened*	55.9%	57.6%	61.9%	62.8%	59.4%

* Includes some semiconductor discretes that comply with MILSTD 750 versus 883.

** The JAN-certified devices include both MIL-S-19500 and MIL-M-38510.

The selection of manufacturers for site visits and interviews was based on the study team's goal of examining several different microelectronic device types and classes used in the radars, while at the same time keeping site visits within cost and schedule constraints. Figure B-II-2 illustrates the relative sample sizes for the parts types surveyed. Site visits were conducted with Texas Instruments, National Semiconductor, Motorola, and Solitron Devices because they were four of the principal manufacturers of radar microelectronic parts. Since National Semiconductor recently acquired Fairchild, it was possible to address Fairchild parts as well as National Semiconductor parts in the same interview. Solitron Devices was selected, since they produced the greatest number of identified hybrid devices. A telephone interview was also conducted with LSI Logic concerning configurable gate arrays (CGA) used in the APSP, since these devices represent the leading-edge application-specific integrated circuit (ASIC) technology being used in any F-16 radar configurations.

C. GENERAL BACKGROUND INFORMATION

Much confusion surrounds the various types of commercial and military-qualified microelectronics devices and the differences in procurement standards and procedures applicable to each category. These differences include purchasing practices, quality

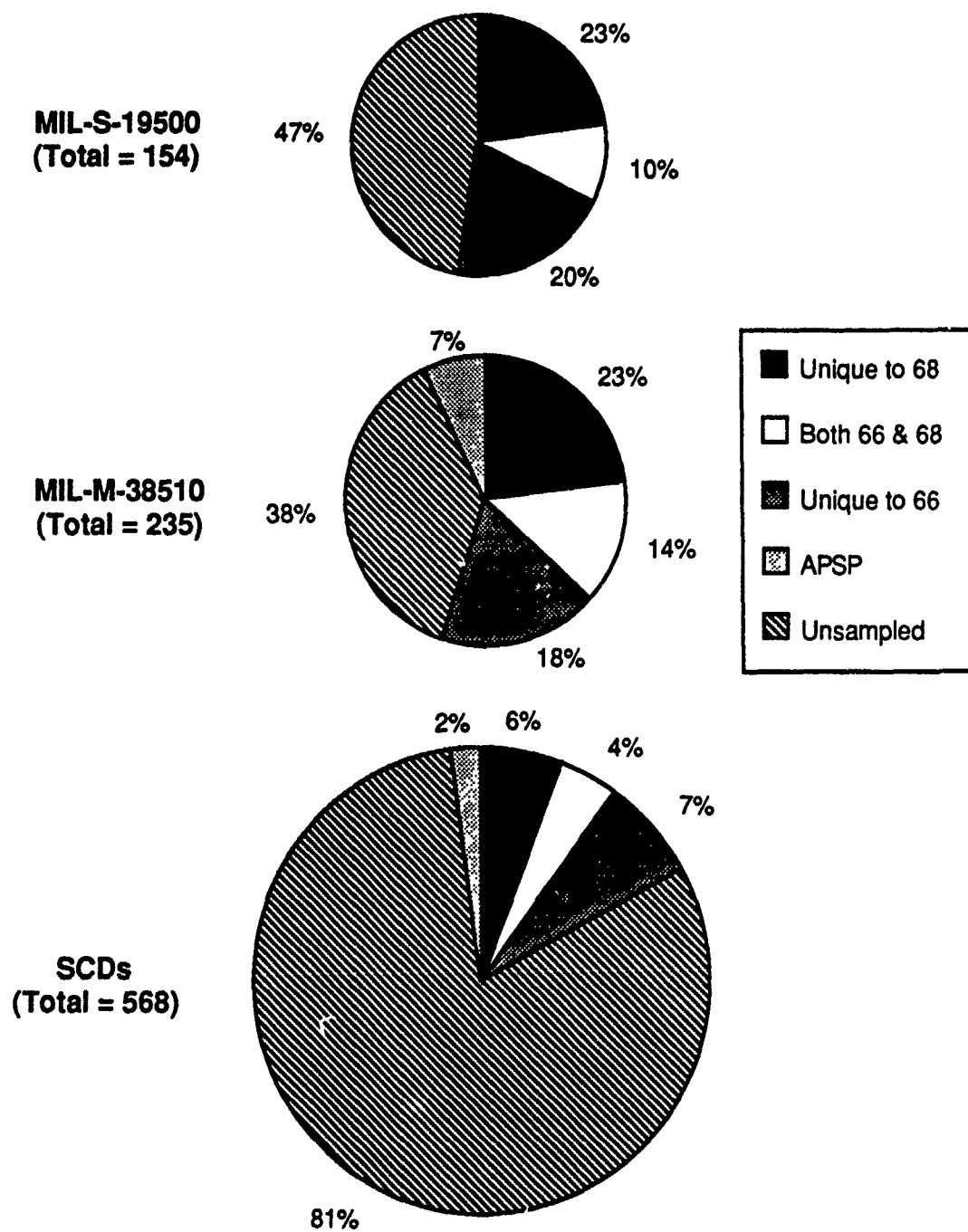


Figure B-II-2. F-16 Radar Parts Types Surveyed.

certification and testing requirements, and defense system requirements. Adding to the confusion is the fact that defense systems may also permit procurement of commercial microelectronic devices under certain conditions. The following section attempts to put these various differences in proper perspective as background for the study findings on foreign sourcing of technologies in microelectronic device areas.

1. Quality Assurance and Certification Requirements

Table B-II-2 groups DoD device types by quality assurance/certification requirements, and provides an overview of permitted fabrication and assembly locations for the various microelectronics device types. In general, for the majority of the *discrete* devices, wafer fabrication occurs in offshore facilities; an exception is JAN¹ devices which must be fabricated onshore. While offshore assembly and test is permitted for *most* JAN device types, JANS² and JANTXV³ type devices must be assembled and tested onshore.

Similarly, the great majority of *microcircuit* devices used in DoD applications are assembled, and to a lesser extent fabricated, offshore. Again, exceptions are the JAN devices that are qualified to MIL-M-38510, which must be both fabricated and assembled entirely onshore, or at a number of audited and certified lines (QPL) offshore. The Standard Military Drawing (SMD) is relatively new and is intended to reduce the number of SCDs that are generated by Original Equipment Manufacturers (OEMs) or System Prime Contractors (Primes). SMD devices are produced in accordance with Government-generated military drawings, whereas SCD devices must conform to OEM requirements. All microcircuit devices, with the exception of the commercial parts (sometimes called "883 look-alikes") must comply with the requirements of MIL-STD-883, *Test Methods and Procedures for Microelectronics*. These "883 look-alikes" will have the packaging and performance characteristics of the fully JAN-certified devices but may come off fabrication and assembly lines that have not been audited by DoD and/or may not meet other criteria established in MIL-M-38510. Only products conforming fully to specification MIL-S-19500 or MIL-M-38510 are referred to as MILSPEC or JAN (these terms are often used interchangeably).

¹ JAN stands for joint Army-Navy standard certification categories.

² JANS devices are the highest JAN certification level and meet space application requirements.

³ JANTXV devices are certified to meet exceptionally rigorous testing and inspection requirements.

Table B-II-2. Device Categories

Semiconductors Discretes	Device Category	Audit Certified By	Die Fabrication	Assembly and Test	Process and Test Requirements
	MIL-S-19500 (JAN, JAN-TX, JANTXV, JANS)	DoD	Onshore	Offshore permitted if possesses onshore certified line (except JANS and JANTXV)	} MIL-STD-750
	Source Control Drawing (SCD)	Manufacturer	Offshore permitted	Offshore permitted	
	Off-the-Shelf Commercial	NA	Offshore permitted	Offshore permitted	At some level below MIL-STD-750
Microcircuits (Including Hybrids)	MIL-M-38510 (JAN B and JAN S)	DoD	Onshore	Onshore	} MIL-STD-883
	DESC/Standard Military Drawing (SMD)	Manufacturer	Offshore permitted	Offshore permitted	
	MIL-STD-883 Microcircuits (Vendor Part Numbers)	Manufacturer	Offshore permitted	Offshore permitted	
	Source Control Drawing (SCD)	Manufacturer	Offshore permitted	Offshore permitted	
	883 "Look-alike" (Commercial)	NA	Offshore permitted	Offshore permitted	At some level below MIL-STD-883

Most MIL-STD-883 (or 883-screened) integrated circuits are assembled offshore, and there is evidence that wafer fabrication for these devices is also moving offshore. There are 53 plants in 15 countries owned by 10 U.S. vendors which produce approximately 75 percent of all MILSTD ICs. The remainder of these ICs are produced in 12 plants in the U.S.⁴

⁴ *Report of The Defense Science Board on Use of Commercial Components in Military Equipment, Office of the Under Secretary of Defense for Acquisition, June 1989.*

2. Price Variations

Significant price differences exist between commercial and MILSPEC device types. Data from the Defense Science Board study, *Use of Commercial Components in Military Equipment*, indicate that both 883-screened and SMD microcircuit-type devices will generally cost roughly four times as much as comparable "rugged commercial" devices. This same report indicates that JAN devices cost approximately 8 times and SCD devices cost approximately 15 times as much as comparable "rugged commercial" devices. Factors influencing these price differentials include standards, economies of scale, and costs of implementing DoD procurement requirements. Factors influencing price variations will be discussed in more detail in Section II, Findings.

3. Unique DoD Weapon System Requirements

DoD weapon systems often have unique operational requirements that are not present in the vast majority of commercial applications. These requirements include general needs such as greater specified operating temperature ranges and higher reliability. However, other DoD microelectronics requirements are system unique to meet specified performance constraints (such as the matching of diodes, or extreme packaging needs). Finally, some unique DoD microelectronics requirements are driven by the need to acquire equivalent spare and replacement devices over life cycles that may range upwards of 30 years from system conception through their useful operational life.

II. FINDINGS

Technology is broadly defined in this portion of the study as the experience, expertise, and/or capabilities necessary to support the fabrication, assembly, packaging, and testing of microelectronic devices. From this perspective, sourcing of foreign technology includes foreign fabrication, assembly, raw materials, manufactured parts, and related test, assembly, and manufacturing equipment. For study purposes, the term "foreign" includes U.S.-owned offshore, foreign-owned offshore, and foreign-owned onshore facilities.

Section II-A describes in detail the identified sources of foreign technologies found for the microelectronic devices in the F-16 radars. Section II-B identifies a number of factors, including various policies and practices, that were found to influence the growing sourcing of foreign technologies.

A. FOREIGN SOURCING

There are many reasons for using foreign technology, and use alone does not constitute dependence or vulnerability. Thus, the data presented in the following paragraphs concentrate on quantifying the levels of sourcing of foreign technologies for specific microelectronic devices, and on highlighting specific technology areas that could constitute potential risks or vulnerabilities if foreign technology were restricted for a period of time.

The data presented covers 334 microelectronic device configurations found in use in the F-16 radars. This represents approximately 35 percent of the microelectronic device-types found in these radars. For the purpose of these discussions, the manufacturing processes are divided into wafer fabrication (sometimes called the "front-end") and packaging and assembly (the "back-end"). Figure B-II-3 provides a short summary of these processes. Of the device-types studied, there were multiple manufacturers identified for 85, bringing the total number of part types in the study data base to 421. The number of microelectronic device configurations used in the AN/APG-68 radar and evaluated in this study represent 2117 parts, or a little over one-quarter of the parts used in the total radar design.

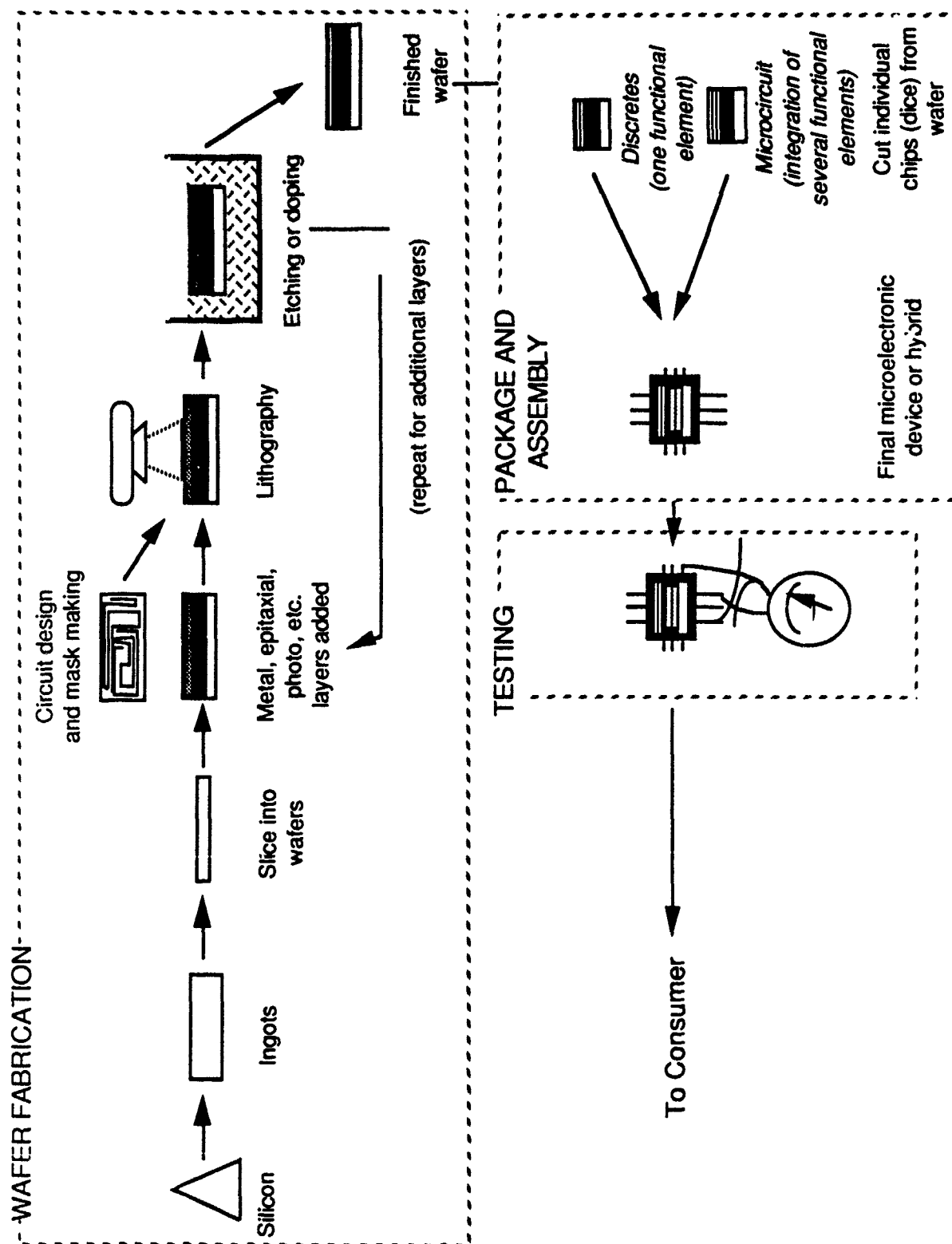


Figure B-II-3. Wafer Fabrication, Packaging and Assembly, and Testing.

Finally, a key factor that should not be overlooked in this analysis is the relative priority placed on onshore sourcing during the design and development of the F-16 radar. Westinghouse personnel indicated that, during initial competition for the contract to develop a radar for the F-16 aircraft, use of foreign sources was perceived as a potential negative factor in the final source selection criteria. In fact, the Westinghouse personnel recalled that portions of the original design concept relied on offshore microelectronic devices. But, as a consequence of the prevailing negative perception regarding foreign sources, the concept was later changed to reduce the use of foreign-sourced microelectronic devices.

As a result of these perceptions and the policies implemented by Westinghouse for this design effort, the level of dependence on foreign technology in the F-16 radar may be less than other DoD weapon systems of comparable microelectronic complexity. This also implies that both the Government and the prime contractor can have an effect on a system's reliance on foreign technology, provided that a specific technology has not already migrated offshore.

1. Wafer Fabrication

a. Facilities

All of the dice for the specific microcircuit devices (excluding the hybrids) used in these systems and evaluated by going to the selected manufacturers (Section I-B) were fabricated in the U.S. However, each of the IC manufacturers visited has offshore wafer fabrication facilities that do provide dice for 883-screened parts. In addition, there were instances of foreign sourcing (NEC, Japan) for two sets of specific diodes identified by Hill Air Force Base personnel. Therefore, the study team doubts that this extremely high percentage of onshore fabrication of dice is representative across the microelectronics suites of DoD weapon systems generally.

Texas Instruments indicated that although all of the dice for the F-16 radar parts discussed came from one of three Texas cities (Sherman, Dallas, or Houston), it has front-end facilities in two additional Texas cities (Lubbock and Midland) and in seven offshore cities--Freising, Nice, Miho, Hatogaya, Taipei, Baguio, and Singapore. National Semiconductor reported that between 75 and 80 percent of its wafer fabrication for both commercial and military purposes is onshore. Motorola stated that all of its JAN wafers are fabricated in Phoenix; however, it fabricates and assembles the majority of its 883-screened products in Malaysia.

The dice for the 14 power-application-type hybrid devices that were evaluated in this study were either fabricated in onshore facilities or acquired from U.S. onshore distributors. A total of 45 different die types were identified as being used in the 14 hybrids studied. Of these dice, 14 were fabricated onshore by Solitron and the other 31 were acquired from U.S. distributors. Approximately half of the dice acquired from distributors were fabricated at U.S. onshore facilities. The distributors indicated that the remaining dice could have come from both onshore and offshore sources, and the only method of determining the source would be to research the specific "diffusion runs" for the actual dice used for each production run of a hybrid device. Time constraints did not permit analyses of distributor sources and the identification of fabrication locations.

b. Materials

Most U.S. die fabrication facilities are dependent on foreign-owned silicon sources. However, other materials needed in wafer fabrication processes (photo plates, pellicles, quartzware, targets, bond wire, and preforms) were generally available onshore.

Both National Semiconductor and Motorola indicated that they are obtaining silicon offshore or from onshore sources owned by foreign companies. However, Texas Instruments manufactures its own polysilicon at its plant in Sherman, Texas. This facility has been growing its own silicon for at least 25 years. Other silicon supply sources identified during this study were:

- SEH, a Japanese-owned company that has five plants in Japan, one in Malaysia, and one in Washington State.
- MEMC, a German-owned company with headquarters in St. Peters, Missouri. It has plants in Spartanburg, South Carolina; Malaysia; and Italy.
- Wacker, a German company located in Burghausen. It also has manufacturing facilities in Portland, Oregon.
- SILTEC, owned by Mitsubishi (Japan). It also has manufacturing facilities in Salem, Oregon.
- OTC (Osaka Titanium), a Japanese company that recently purchased two U.S. locations that provide silicon wafers: Cincinnati Milicron and US Semi.
- Reticon, a U.S. company located in Pottstown, Pennsylvania. It was identified as a source for wafers used in the fabrication of discretes.
- NBK, recently purchased by Kawasaki (Japan). It has manufacturing facilities in Santa Clara, California.

c. Manufacturing Equipment

The IC manufacturers that were visited all indicated a high degree of dependence on Japanese lithography equipment, although a few U.S. companies were mentioned as potential sources for lithography and stepper equipment. All other wafer fabrication equipment appears to be available from onshore sources.

Canon and Nikon, both Japanese companies, were the most frequently mentioned sources of lithography equipment. Other stepper companies mentioned include: GCA (General Signal), a U.S.-based company; Ultratech (also General Signal), a U.S.-owned company; and ASM, a Dutch-owned company.

One of the IC manufacturers indicated that there were very few incentives to acquire steppers from relatively small producers like GCA (with an estimated capacity of approximately 60 units per year) when they could deal with Nikon (with an estimated capacity of approximately 500 units per year). The principal reason was the greater confidence of the manufacturer in the large producers' future. Interestingly, the current *yearly* capacity of Nikon approximates the *total* installed operating units produced by either Ultratech or GCA today.

IC manufacturers visited indicated that they have more confidence in the equipment produced offshore because of the manufacturers' better reliability, quality, and service and their general concern over the future of U.S. companies. At the same time, there exists a general belief among those visited during this study that U.S. component manufacturers do not receive "first-line" Japanese manufacturing equipment. They perceive that the Japanese equipment manufacturers provide "state-of-the-art" equipment to Japanese firms first, thereby keeping U.S. companies one generation behind.

The Japanese have been very aggressive in many other equipment areas, including electron-beam (E-beam) and focused ion-beam equipment for lithographic photomask making and direct-write on the wafer substrate, integrated circuit test equipment, ion implanters, and deposition equipment. U.S. firms in these areas generally are relatively small and undercapitalized. Therefore, there are reasons to be concerned that the future availability of U.S. capabilities in these areas may be vulnerable.

The risks inherent in eroding U.S. capabilities in semiconductor manufacturing have been examined in other studies. A recent IDA study concluded:

The international market for lithography is at a critical threshold. While Japanese industry is pursuing actively both optical and X-ray approaches

using research consortia and guided by a national goal, U.S. lithography equipment companies are struggling to stay in business. Failure to meet this challenge would be a substantial disadvantage for U.S. lithography equipment suppliers and semiconductor manufacturers.

The study team found that the recommendations of this same IDA report are still valid; they state that a coherent DoD program should be established for supporting and promoting microelectronics manufacturing technology:

DoD needs to channel resources in this area effectively based on a strategic view of requirements. Currently such an overall understanding of microelectronics technology requirements does not exist. The specific concerns of such a program should be:

- (1) Identify areas of dependency in microelectronics infrastructure which DoD should address, determine the manner by which this dependency should be resolved, and fund programs to alleviate these dependencies;
- (2) Determine what long-term programs for underpinning the semiconductor industry infrastructure are the responsibility of DoD and lay out the program plan for its support.
- (3) Identify and implement means to use maximally commercial technology in DoD systems and reduce the reliance upon specific devices;
- (4) Identify those areas in which fundamental DoD needs cannot be met by commercial industry and develop the program plan for meeting these requirements.
- (5) Integrate and interrelate DoD's support of SEMATECH to the overall DoD microelectronics strategy and requirements. This should be understood to be a two-way street: DoD should plan on and make every effort to get SEMATECH-developed technology transferred to its microelectronics suppliers (and, thus, it should work with SEMATECH to ensure that the technology being developed there benefits DoD, as well as domestic commercial industry), and DoD should make the results of its sponsored research in semiconductor manufacturing available to SEMATECH.⁵

2. Packaging and Assembly

a. Facilities

The study found a significant portion of the F-16 radar parts types were assembled offshore. Tables B-II-3, B-II-4, and B-II-5 present three slightly different views of these

⁵ R.H. Van Atta et al., *Microelectronics Manufacturing Technology: A Defense Perspective*, Institute for Defense Analyses, IDA Paper P-2097, March 1988.

collected data. Table B-II-3 compares the various percentages of onshore and offshore assembled parts types for all the data collected in the study. Table B-II-4 compares this same information for the AN/APG-68 radar only, with the data adjusted to remove the influence of multiple manufacturing sources for the same part type. Finally, Table B-II-5 compares percentages of onshore and offshore assembled parts (by quantity) in the AN/APG-68 radar, and again data are adjusted to remove duplication of multiple sources for the same part type.

Table B-II-3. F-16 Radar Parts Types Assembled Onshore and Offshore

	Percentage Assembled	
	Onshore	Offshore
SCD	32.1	67.9
MIL-M-38510	100.0	0.0
MIL-S-19500	54.7	45.3
Totals	71.7	28.3

Table B-II-4. AN/APG-68 Radar Parts Types Assembled Onshore and Offshore, Adjusted for Multiple Sources of Identical Parts Types

	Percentage Assembled	
	Onshore	Offshore
SCD	47.0	53.0
MIL-M-38510	100.0	0.0
MIL-S-19500	30.5	69.5
Totals	67.1	32.9

Table B-II-5. AN/APG-68 Radar Parts (by Quantity) Assembled Onshore and Offshore, Adjusted for Multiple Sources of Identical Parts Types

	Percentage Assembled	
	Onshore	Offshore
SCD	25.3	74.7
MIL-M-38510	100.0	0.0
MIL-S-19500	46.0	54.0
Totals	65.5	34.5

These tables show that 28.3 percent of the F-16 radar device configurations evaluated in this study were packaged and assembled offshore. However, the offshore percentages increase significantly--to 45.3 percent and 67.9 percent for MIL-S-19500 and SCD part types, respectively--when the MIL-M-38510 parts types (MILSPEC parts which are restricted to onshore assembly) are removed. Data from Table B-II-5 reveal that approximately 34.5 percent (by quantity) of the parts surveyed for the AN/APG-68 radar were assembled in offshore facilities.

Approximately 26 percent of F-16 radar IC device configurations evaluated in this study were packaged and assembled offshore. However, the offshore percentage increased significantly--to 84 percent--for SCD parts produced and screened in compliance with MIL-STD-883.

The 14 hybrid devices evaluated in this study were all power application devices. These devices are very specialized, low-thermal-resistance, custom power hybrids for military and aerospace applications. The hybrid manufacturer visited during this study, Solitron Devices, produces its own packages, and assembles the hybrids in its Florida facility. Westinghouse personnel observed that there exist very few power-related-hybrid producers that meet the military specifications, and that this technology is critical to DoD weapon systems. Solitron personnel indicated that at the present time their products essentially constitute a niche-market, and they do not face significant competition with offshore sources.

In discussions going beyond the sourcing of specific microelectronic devices for radars, Texas Instruments personnel made a number of observations about the location of fabrication and assembly operations in general. They indicated that virtually all (99+ percent) of their JAN B and JAN S parts are assembled in their Midland, Texas, facility. National Semiconductor personnel noted that between 70 and 80 percent of the assembly and testing of their military components is offshore. The National spokesman went on to observe that approximately 98 percent of their commercial assembly and testing is done in offshore facilities. The bulk of this assembly and testing is done in National's Singapore facilities, where only 10 percent of the output is for military applications. Motorola indicated that almost all of its JAN devices are assembled onshore. However, many of the 883-screened devices are assembled in Malaysia.

b. Materials

The microelectronic devices evaluated in this study were found to be almost totally dependent on foreign sources for packaging materials. The primary items dependent on foreign sources were (1) ceramic packages, lids and covers, and lead frames used on semiconductor and IC devices, and (2) ceramic feedthroughs used on power hybrid devices.

While the majority of lead frames for the devices evaluated in this study are manufactured onshore, the data indicate an increasing trend toward sourcing these parts offshore (Table B-II-6). The full extent of this trend may be masked by the fact that National Semiconductor's subsidiary, DynaCraft (located onshore), produces the majority of National's lead frames, including those used in their offshore assembly facilities.

With few exceptions, the ceramics were all acquired from offshore sources or from sources in the U.S. that are foreign owned. The primary source for ceramics is Kyocera, a Japanese manufacturer. Kyocera has plants in both Japan and San Diego. The study team received conflicting views during the visits relative to the responsiveness of Kyocera. One source indicated that Kyocera is very responsive to its needs, while another indicated that Kyocera had (on several occasions) unilaterally altered critical specification properties that ultimately affected device quality.

Other ceramic package manufacturers included NTK, Naruni, and MPI. NTK and Naruni are Japanese companies located in Japan. MPI is a U.S.-owned company with all of its manufacturing performed in Singapore.

While ceramic packages are critical to DoD weapon system applications, they are also needed in many commercial applications. One microelectronics manufacturer estimated that only about 20 percent of worldwide ceramic packages are used in military weapon system applications. Again, as with most of the microelectronics technology areas, the commercial market place is the driving force behind requirements.

Most covers (caps and lids) were acquired from the same manufacturers that provided the ceramic packages. The primary differences indicated by the percentage changes in Table B-II-6 are due to the U.S. sources for metal cans and for side-brazed lids.

While each of the manufacturers expressed the desire to support onshore sources for ceramics and covers, each acknowledged that simple economic factors coupled with source availability favored offshore suppliers.

Table B-II-6. Sources of Packaging/Assembly Materials

		Lead Frame		
		APG-66	APG-68	APG-68 (new)*
883 on shore	(%)	86	80	68
883 off shore	(%)	14	20	32
38,510 on shore	(%)	99	81	70
38,510 off shore	(%)	1	19	30

		Ceramic Base		
		APG-66	APG-68	APG-68 (new)*
883 on shore	(%)	0	0	0
883 off shore	(%)	100	100	100
38,510 on shore	(%)	2	1	1
38,510 off shore	(%)	98	99	99

		Cover		
		APG-66	APG-68	APG-68 (new)*
883 on shore	(%)	5	8	9
883 off shore	(%)	95	92	91
38,510 on shore	(%)	5	17	26
38,510 off shore	(%)	95	83	74

* Parts in the new configuration APG-68 and not used in the APG-66.

c. Assembly Equipment

All the microelectronics manufacturers visited during this study indicated that U.S. sources could be found for assembly equipment. The sources for assembly equipment used in the various facilities varied significantly, and there was general consensus that the specific equipment choices were justified on a case-by-case basis that focused on economic as well as availability factors.

While the study team tracked the origins of specific parts, it also investigated the use of foreign production technology in U.S.-made components. If a product is "Made in USA" but can only be produced by using equipment from abroad, the possibility of dependence clearly exists.

Assembly equipment for microelectronic devices includes the saws used for wafer-cutting, furnaces, and various bonders, welders, and soldering equipment. IDA's survey of four companies found that the degree of use of foreign equipment varied markedly, depending, in part, on whether the equipment is used for MIL-M-38510 or 883-screened components. In general, the assembly that takes place offshore uses foreign equipment. This equipment tends to represent the "state of the art" available to U.S. manufacturers, and its use offshore is driven by the high volume of both commercial and 883-screened products assembled there.

The extent of foreign equipment used in the assembly of all MIL-M-38510 parts and the relatively small fraction (less than 25 percent, based on DESC data) of 883-screened parts assembled onshore varies by company. Texas Instruments produces almost all its own assembly equipment for its JAN parts. National has a mix of U.S. and foreign sources for its assembly equipment. Motorola indicated that it relies extensively on foreign equipment in its assembly process.

More important than the individual pieces acquired offshore is the perception among those who rely on foreign suppliers that they may not receive the "state-of-the-art" equipment, but rather the next-older generation. This perception, which IDA analysts did not attempt to validate because of time constraints, is that Japanese manufacturers in particular favor their domestic colleagues with the newest equipment. At present, it can take 6 to 9 months to receive new assembly equipment from the Japanese manufacturers. While there may be domestic suppliers of the equipment, they are often at a price disadvantage and, perhaps more importantly, may suffer from an uncertain future.

3. Adverse Factors in the Business Environment

a. Cost Drivers

Three specific cost factors (offshore labor rates, quality assurance cost burden, and DoD cost accounting standards) are creating an environment in which (1) it is becoming extremely difficult for onshore microelectronics manufacturers to compete with offshore sources, and (2) DoD OEMs must look to offshore microelectronics manufacturing sources to keep costs low.

Even between different categories of military-qualified devices, there is a wide variation in market prices for high-reliability microelectronic devices because of the differing levels of screening and testing costs involved. Table B-II-7 compares the typical cost differences for a hermetically packaged large-scale integrated (LSI) circuit for three levels of screening and testing. The die in this example is approximately 50,000 square mils and is being assembled in a 5 dollar, 64-pin package. The total costs and typical yields are displayed in this table for three categories: commercial, MIL-STD-883 Class B screened, and full MIL-M-38510 level [on Qualified Parts List (QPL)].

Table B-II-7. Semiconductor Pricing Factors*
(Assembly Costs in Dollars)

Category	Commercial	Screened	QPL
Die Cost	2.00	2.00	2.96
Package Cost	5.00	5.00	5.00
Assembly Cost	0.44	2.22	2.22
Pre-Cap Visual	0.00	0.15	0.31
Pre-Cap Yield (3%)	84%	71%	63%
Assembled Cost	8.86	13.27	16.64
Screening	0.00	0.72	0.82
Pre-Burn-In Test	0.00	0.23	0.46
Pre-Burn-in Yield (%)	100%	74%	70%
Burn-In Cost	0.00	0.64	1.10
Final Test Cost	0.23	0.68	2.28
Final Test Yield (%)	84%	88%	87%
Qualification	0.00	0.00	5.70
Factory Cost	10.84	23.32	39.93

* Source: *Semiconductor Economics Report*, Vol. 3, No. 9.

As seen from this table, the added cost of labor and the significant yield losses at each of the screens (e.g., see data for "pre-cap yield") can greatly increase the cost of the devices. In the absence of a contractual requirement, weapon system OEMs, driven by a desire to minimize costs, have little incentive to select the QPL device over the comparable 883-screened device (which is generally assembled and sometimes fabricated offshore).

Finally, the most significant factor influencing offshore packaging and assembly of integrated circuits is the low offshore labor rates. Recourse to lower offshore labor costs is not an *alternative* to automation onshore, but an incremental advantage of locating offshore, since the maximum amount of automation for typical assembly operations (probing, die separation, wire bonding, etc.) is already being installed in offshore facilities.

Differences in total assembly costs in the range of 1 to 2 cents per device, as shown in Table B-II-8, do not appear significant until production volume figures are considered. Large onshore assembly facilities frequently have production yields that average roughly one million per month, whereas offshore facilities have production yields in the ranges of 30 to 100 million per month.

**Table B-II-8. Assembly Cost Comparison,
Automated 16-Pin Plastic Packages***

Assumptions	U.S.	Overseas
Cycle Time	5 days	20 days
Labor Rate	\$7.00 per hour	\$1.50 per hour
Die and Package Cost	\$0.23	\$0.23
Typical Costs		
Assembly/Test	\$0.081	\$0.056
Maintenance/Overhead	\$0.024	\$0.017
Work in Process	\$0.00031	\$0.0013
Brokerage Fees		\$0.004
Air Freight		\$0.015
Total Costs	\$0.383	\$0.367

* Source: *Semiconductor Economics Report*, Vol. 3, No. 9.

b. Quality Drivers

Given the massive quantities of microelectronic devices being produced in offshore facilities, the skills and knowledge (technology) necessary to produce high-quality devices in high volumes are moving offshore. With production yields ranging up to 100 million per month at some offshore microelectronics manufacturers' facilities, quality defects cannot be tolerated. In addition, the larger volumes provide more statistically significant information in shorter time spans, thus creating an environment for good statistical process control (SPC) techniques.

Manufacturers interviewed noted that there are few high-volume operations in the U.S. that compare with the high-volume offshore facilities. They also felt that the skills and knowledge necessary for high-quality production now resides at various offshore facilities, on the basis of the massive number of parts assembled at offshore facilities. They cited examples where they consciously train managerial and technical personnel for onshore facilities through exchanges with offshore facilities.

B. INFLUENCE OF POLICIES AND PRACTICES

1. OEM and System Program Office Acquisition Practices

The parts selection trends for the evolving F-16 radar configurations have been away from the DoD MILSPEC parts.

The findings within Section II-A, Foreign Sourcing, are based on an analysis of Government documentation, drawings, and military specifications. According to this documentation (Table B-II-1), approximately 44 percent of the AN/APG-66 radar design consisted of MILSPEC type microelectronic devices. The percentage of MILSPEC parts fell when Westinghouse evolved the radar to the AN/APG-68. It is interesting to note that the percentage of MILSPEC parts that were unique to the new AN/APG-68 configuration dropped to approximately 38 percent. The trend away from MILSPEC parts is also demonstrated in the unique APSP parts.

It should be noted, however, that the "as-built" configuration often varies from that in the documentation, because of waivers, deviations, etc. Furthermore, the study team did not attempt to determine all of the quantities of each of the respective device configurations actually used in the various radar configurations. However, the observation that the trend is away from MILSPEC parts is consistent with data obtained from the Defense Electronics Supply Center (DESC).

Semiconductor and integrated circuit manufacturers often do not have insight into the OEM's selection of parts (MILSPEC, SCD, 883-certified, etc.) to be used in a system. However, it was their perception that the vast majority of microelectronic devices going into new systems are produced offshore (i.e., they fall into the 883-screened category) and most of the spare and repair parts needed during the life of a system that are acquired by DESC fall into the MILSPEC category. Several of the IC manufacturers cited examples where they have assumed the cost of developing and certifying a MILSPEC part (on the urging of both the Government and a system prime), only to have the prime select an 883-screened device for his design. The IC manufacturers observed that if DoD wants MILSPEC parts (that are produced onshore), this requirement needs to be specified in contractual terms, as well as enforced through contractual vehicles to the OEMs.

An earlier IDA study concluded, on the basis of interviews with industry officials, that DoD may be in a better position to influence the U.S. electronics industry to use domestic sources by offering incentives to industry.⁶

2. DoD Quality Requirements

There was a broad consensus among IC manufacturers visited that DoD's initiative to reduce costs of certifying microelectronics to specified quality assurance requirements will achieve its goal. However, there is evidence that this initiative will also exacerbate DoD's dependence on offshore fabrication and assembly of microelectronic devices.

DoD quality assurance programs focus on identifying the requirements in the appropriate specifications, and assuring that the quality of the respective devices meets the specified requirements. Because of the complexity of these devices, testing of finished product alone will not assure that the needed high quality and high reliability are present in the product. Therefore, over time, comprehensive certification processes have evolved to ensure that the microelectronic devices meet essential military requirements.

At present, the highest levels of product quality assurance for microelectronic devices are referred to as MILSPEC (or JAN) parts and are specified in MIL-S-19500 and MIL-M-39510 for discrete and microcircuit devices, respectively. Of the 53,876 active National Stock Numbers (NSN) tracked by the DESC for discrete devices, only 6.6

⁶ R.H. Van Atta, E.H. Heginbotham, F.R. Frank, A.J. Perrella, and A.W. Hull, *Technical Assessment of U.S. Electronics Dependency*, Institute for Defense Analyses, IDA Paper P-1841, November 1985.

percent, or 3,564, are MILSPEC. Furthermore, of the 88,246 active NSNs tracked by DESC for the microcircuit devices, only 2.7 percent, or 2,396, are MILSPEC.

The JAN qualification process can take 1 to 2 years to complete, and the cost of full certification may range from \$40,000 to \$500,000, depending on the complexity of the processes involved. This qualification process addresses only a single specific device type, and each new device, in order to be certified as JAN and put on the DoD's Qualified Parts Lists (QPLs), must go through this process.

DoD is currently developing a new quality assurance concept that will focus on the microelectronic device manufacturer's process controls in support of a Qualified Manufacturers Listing (QML). The QML concept will qualify a company's lines and processes, and thereby all of the microelectronic devices produced on those lines.

The QML concept was first examined for application to hybrids (MIL-H-38534 and MIL-STD-1772). DoD is currently attempting to extend this concept to integrated circuits. However, many in the microelectronics industry expect that the extension will prove more difficult because (1) hybrid manufacturers are primarily military suppliers with capitalization needs often less than \$100 million, and (2) the military market for integrated circuits is only 7 to 10 percent of the commercial market, based on value (and even less if based on quantity), and it generally requires more than \$300 million to set up and run an integrated microcircuit manufacturing plant.

IC manufacturers visited during this study were all very supportive of this new concept because it would reduce the cost of their products and streamline the certification process without adversely impacting product quality. Often cited as another benefit related to the QML concept is the potential to reduce the burden of source inspections. DoD regulations require that Government contractors audit each supplier, and the cost of the audits (sometimes as many as 80 audits per year for large microelectronics manufacturers) must be passed on to the customers.

The Government Procurement Committee (GPC) of the Semiconductor Industry Association (SIA) recently took the following position on the QML concept:

The QML system, to be effective, should be applied to all of the industry's factories, both onshore and offshore, and to all technologies, new and old. However, it must be recognized that once the QML system has progressed to offshore facilities and subcontractors can purchase QML products made in foreign countries, the volumes of like product produced in onshore facilities will drop, U.S. assembly and test factories will close, and our U.S. industry base to support our national defense will disappear. Under

the current system it is the QPL and the order of precedence that is keeping some production onshore.

To understand why QML will drive product offshore, one should recognize that offshore production is now 95 percent commercial, and military overhead costs are shared with the commercial volume and market demand. Military product runs in the same factories enjoy a much lower overhead cost burden than does products produced on U.S. lines. Onshore product will always carry a "premium" for this reason, unless consistent and increasing volume can be maintained. Onshore product prices, then, being higher than offshore, will force procurement of QML product produced offshore and drop onshore volume, forcing manufacturers to close factories, or at best to raise prices on any remaining low volume left on U.S. lines [e.g., product for space application (Class "S")]. As volume diminishes, manufacturers may well drop entire lines and use available onshore square footage for alternate expansion.⁷

The semiconductor discrete and IC manufacturers visited all agreed with the SIA position paper. They went on to conclude that if DoD decides to put both QML and JAN parts at the same level in the order of precedence for parts selection, the onshore JAN facilities will close down. Although they favor the QML concept, they also believe that the new QML concept will exacerbate current foreign dependence problems if foreign sources are permitted to participate.

3. Cost Accounting Standards

Current cost accounting practices raise the cost to DoD of parts, making them less competitive with parts produced offshore. These cost differentials create an incentive for OEMs to bypass JAN or QPL parts and opt for 883-screened parts (often from offshore sources) or other parts that are not subjected to these practices, unless JAN parts are contractually required.

Federal Acquisition Regulations (FAR 15.804) require separate cost accounting on a Standard Form 1411 for products (including microelectronics) with a negotiated contract that is expected to exceed \$100,000. In addition, many Defense-related primes require the 1411s even when the negotiated price will be well below the specified threshold. This separate cost accounting for a specific microelectronic product often requires that a manufacturer separate military and commercial productions. Due to lower volumes, military-dedicated microelectronic production lines are not generally fully loaded and may not even run continuously. These conditions create higher overhead costs per unit and

⁷ Semiconductor Industry Association/Government Procurement Committee, Position Paper, G. Cohrt, Chairman, Summer 1989.

longer delivery times. Microelectronic manufacturers are concerned that these regulations contribute to the problem of making onshore-produced microelectronics even less competitive with foreign (offshore) sourced devices (that reflect sale prices quoted to the general public).

The Defense Acquisition Regulation Council is currently processing a case that is looking into the possibility of expanding the range of exemptions for cost and pricing data. The case, known as the "1412" (the Standard Form used to claim exemptions), is considering options that will permit price quotes to reflect sale prices to the general public. A final ruling on this case is still 6 to 12 months away.

4. ITAR and EAR Restrictions

Export control regulations, the International Traffic in Arms Regulations (ITAR) and the Export Administration Regulations (EAR), are designed to achieve the national security and foreign policy objectives of withholding weapons and military-related dual-use technologies from specific foreign destinations. By their very nature these regulations are impediments to trade in technology and technology products, but they have been accepted as necessary to achieve these other objectives. The laws establishing these controls (the Arms Export Control Act and the Export Administration Act) specifically state that they should be implemented and administered so as to minimally interfere with commerce. Concerns have been raised by the semiconductor industry in the U.S. that, as implemented by the Department of Commerce, the Department of State, and DoD, these regulations may excessively and unfairly inhibit U.S. exports of microelectronics and systems containing microelectronic devices, and thus adversely affect both U.S. semiconductor device makers and the U.S. semiconductor equipment industry.

The concerns, as stated by semiconductor industry representatives, include the following:

- Foreign sales restrictions, particularly those involving unilateral "West-West" controls, have permitted foreign competitors to gain market access abroad at the expense of U.S. companies.
- Problems of longer and less predictable license review processes in the United States, compared to those practiced by the governments of foreign competitors, give advantage to foreign competitors in marketing abroad.
- Commercial capabilities to produce devices with performance equal to those restricted by the international agreement (COCOM) has spread to several

countries not adhering to these controls, raising concerns regarding the applicability and value of such controls.

Moreover, it is noted that commercial semiconductor devices available both in the U.S. and in many foreign countries are several generations more advanced than those generally used in most defense systems. Given the worldwide distribution of many of these commercial products, from globally dispersed companies, the concern is that such commercial devices may be obtainable despite such control efforts. U.S. semiconductor firms have expressed concerns that rigorous efforts, particularly by DoD, to make the export control system work effectively in the U.S., while less concerted efforts are adopted by others, puts them at a marked disadvantage in the international commercial arena. This in turn is seen as decreasing U.S. semiconductor companies' abilities to maintain a competitive position.

5. R&D Funding

DoD's normal mechanism to ensure funding for independent research and development (IR&D) is not applicable to subtier component and equipment manufacturers.

In general, research and development being applied to microelectronics fabrication and assembly equipment, or to critical materials or processes, must come from a percentage of the product sales. Although microelectronics technology has been cited as a most important fundamental building block of today's complex weapon systems, there is no stable process or means of assuring a continuous source of critical R&D resources to this important technology group.

At present, R&D funds are included as allowable costs against contracts to weapon system primes; however, these funds do not find their way down through several tiers of contracting to the microelectronics manufacturers, the processing equipment suppliers, or the material sources.

III. CONCLUSIONS AND RECOMMENDATIONS

The study team concluded that if DoD wishes to reduce foreign technology sourcing and dependence in microelectronics, it requires a comprehensive approach to reduce the influence of a range of systemic difficulties tending to drive technology offshore. It is unlikely that the solution to only one area will alter this trend. Ironically, many of these systemic problems are a result of U.S. Government intervention intended to mitigate other general problems or concerns.

The DoD and the Department of Commerce (DoC) need to develop a comprehensive strategy jointly that addresses microelectronics competitiveness as well as foreign technology dependence. Such a holistic approach should address the following specific areas: sourcing policies; DoD requirements, practices, and programs; and R&D opportunities.

A. SOURCING POLICIES

The Under Secretary of Defense for Acquisition should direct the armed services to enforce existing policies that establish the order of precedence for microelectronic component selection in DoD weapon systems.

As indicated in Findings (Section II-B-1), parts selection trends are away from MILSPEC parts predominantly produced at domestic sources and toward SCD and 883-screened part types that predominantly rely on foreign fabrication and assembly operations. A significant factor influencing this trend is the high cost of MILSPEC parts. On the average, MILSPEC parts cost approximately four times as much as comparable 883-screened devices that are sourced offshore because of the combined effects of the following: (1) lower volume of MILSPEC production quantities, (2) increased cost burden of both quality assurance and cost accounting standards amortized over lower quantities, and (3) lower offshore labor rates.

Enforcement of the order of precedence for microelectronic component selection by primes will increase the volume demand for onshore-produced MILSPEC parts.

Therefore, if the existing order-of-precedence policies are enforced across DoD, the results will reduce the reliance on foreign microelectronics manufacturing as well as reduce the individual MILSPEC parts costs due to economies of scale. Finally, it will also have the tendency to reduce long-term weapon system support costs through the standardization of parts types.

B. DOD REQUIREMENTS, PRACTICES, AND PROGRAMS

(1) The Defense Acquisition Regulation Council should give greater priority to efforts to develop and implement a solution for the burdensome cost accounting practices imposed on microelectronics.

The separate cost accounting practices imposed by the FAR (Section II-B-3) are, in effect, raising the cost of conducting business with DoD. The DARC Case 1412 is investigating options that will permit microelectronics manufacturers to submit price quotations that reflect current sale prices quoted to the general public. If implemented, this exemption from detailed cost and pricing data will reduce the costs of MILSPEC parts and help make U.S.-produced microelectronics more price competitive with offshore products.

(2) The Under Secretary of Defense for Acquisition should direct DESC to restrict the new proposed quality assurance concept (QML) to onshore sources.

There is significant concern on the part of the SIA as well as the IC manufacturers visited during this study that the QML concept (as currently structured) will exacerbate the DoD's reliance of foreign-sourced microelectronics (Section II-B-2). The current QML concept does not specifically restrict the certification of offshore facilities, yet it would propose to put both QML and MILSPEC parts at the same level in the order of precedence for parts selection. The concerned parties strongly believe that this set of conditions will make offshore QML parts the most cost competitive, thereby causing the total dismantling of the onshore MILSPEC quality process.

The microelectronics manufacturers agree that a QML concept that is restricted to onshore manufacturers will reduce the cost of devices to DoD and primes, and will make the onshore products (at specified quality levels) more price competitive with offshore 883-screened parts. However, if the QML is allowed to be applied to foreign facilities, the onshore QML facilities will have the same difficulty competing with comparable offshore facilities.

C. R&D OPPORTUNITIES

(1) The Under Secretary of Defense for Acquisition should initiate a series of microelectronics technology packaging and assembly studies. These studies and research efforts should specifically address new materials and processes that are applicable to DoD high-quality/reliability requirements and also lend themselves to high-volume competitive production manufacturing processes.

The most significant microelectronics foreign technology dependence area discovered in this study and supported by the F-16 radar data was in the materials areas for the packaging and assembly of devices. Furthermore, there was no indication that this trend was likely to change.

(2) DARPA should investigate opportunities to develop a Government policy as well as a process that funds R&D for critical technology areas that are becoming dependent on foreign sources.

Because R&D funds are included as allowable costs against contracts to weapon system primes, these funds do not find their way down through several tiers of contracting to the microelectronics manufacturers, the processing equipment suppliers, or the material sources (Section II-B-5).

(3) DARPA should fund a program in advanced microelectronic lithography that supports development of domestic technology for the range of lithographic processes needed for defense applications in the 0.5 μ to 0.25 μ feature sizes.

These programs should include extensions of current optical technologies (excimer laser, deep ultraviolet), direct-write electron beam technology, compact ("granular") soft X-ray technology, and the mask technologies required for these lithography tools.

APPENDIX B, ANNEX III

**AIM-7 SPARROW AND AIM-120A AMRAAM
AIR-TO-AIR MISSILES**

Joseph M. Ruzzi

Stephen N. Wooley

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EXECUTIVE SUMMARY

This report compares two missile systems, the AIM-7 Sparrow and the AIM-120A AMRAAM. Both of these missiles are designed for medium-range air-to-air combat, with an onboard radar unit to direct a missile to its target. The Sparrow was originally designed in the early 1950s but has undergone several enhancements since its initial deployment. The missile that was designed to replace it, the Advanced Medium-Range Air-to-Air Missile (AMRAAM), representing mainly 1980s technology, has been in low-rate production since 1988.

The U.S. retains the technology leadership central to designing and producing a missile system such as the AMRAAM. In part for this reason, little offshore sourcing of *parts and components* was found in either the AMRAAM or Sparrow at the first and second tiers of supply. Minimal foreign sourcing was found in components central to the operation of the systems. From vendors at lower levels the study team found evidence that foreign sourcing of components and materials occurs with greater frequency, but the team did not have time for thorough investigation below the third tier of vendors. Preliminary indications are that lower tier components (especially microelectronic discrete and integrated circuit devices) are produced or packaged and tested offshore. Chief among the foreign-sourced parts and components were ceramic packages for microcircuits, and certain gallium arsenide substrates. Development of a domestic source for these items would require a year or more, according to contractor estimates.

In contrast to parts and components, *process equipment* required to produce many of the mechanical and electronic components in the missiles was found to be procured extensively from offshore. One prime missile producer reported that 80 percent of its missile machine tools, by value, is from foreign sources. One AMRAAM subsystem producer said it acquired 100 percent of its machine tools from offshore. Whether U.S. suppliers could supply key machine tools that would meet and hold tolerances required for AMRAAM production, and do so in less than the 3 years estimated by the missile prime to be the minimum required to develop a domestic source, was subject to conflicting claims that could not be resolved in the time available.

Some materials required for missile production come from a single foreign supplier or a limited number of foreign suppliers, such as chromium from southern Africa and titanium from Australia. The possibility of supply disruption could be met by stockpiling or possibly, over a longer term, a technological solution such as the development of an alternative material.

The amount of foreign parts and components sourcing is higher in AMRAAM than in Sparrow. This is partly due to the fact that AMRAAM has a much more complex electronics suite than Sparrow. Decisions to procure offshore components are not technology dependent but have been based almost exclusively on the cost advantages of foreign-source componentry. In the cases analyzed, the study found that the U.S. has the capability to manufacture the items required but is not currently price competitive.

This system study makes several recommendations regarding possible actions that the DoD should undertake if it desires to reduce foreign sourcing. Included in the recommendations are that the appropriate DoD authorities should:

- Replace the conflicting and contradictory laws and regulations regarding foreign sourcing with a coherent policy
- Support the industrial base required for high-technology raw and semifinished materials
- Eliminate or modify conflicting and confusing technical specifications
- Reduce the amount of audits and paperwork required of manufacturers.

I. INTRODUCTION

A. FOCUS

The AIM-7 "Sparrow" missile and the AIM-120A Advanced Medium-Range Air-to-Air Missile (AMRAAM) perform roughly similar missions: radar-guided (Sparrow has a semiactive radar, AMRAAM an active radar)¹ medium-range air intercept of hostile aircraft. Although there are major differences between the two designs and the componentry used, AMRAAM has been designed as a follow-on to Sparrow, and as a result it bears some resemblance to its predecessor. Figure B-III-1 provides a graphic illustration of the components and processing tools that are sourced from foreign sources. Figure B-III-2 provides a flow chart of the primary contractors and subcontractors in the two missile programs.

Sparrow and AMRAAM were chosen for this study because of their importance to the U.S. air superiority mission, and because of system designs that represent different points in time. Sparrow, although designed in the mid-1950s, embodies mainly 1970s technology, and AMRAAM represents largely 1980s technology. Continual upgrades to Sparrow have updated its technology relative to AMRAAM. For example, AIM-7P did not enter full-scale development (FSD) until 1987; thus some areas of its technology are equivalent to AMRAAM's. Still, an older design has somewhat limited the incorporation of new technology.

AMRAAM will add three important new capabilities. First, it has beyond-visual-range capabilities; i.e., pilots do not necessarily have to sight the target visually before firing AMRAAM. Second, AMRAAM is also designed to perform in more severe weather conditions than Sparrow. Finally, AMRAAM is designed for launch-and-leave capabilities against multiple targets, while the semiactive guidance of Sparrow requires the pilot of the attacking aircraft to illuminate the target until the missile reaches it. AMRAAM is currently in low-rate production, with the 400 missiles of Lot 1 due by the end of the year.

¹ An active radar system has both transmit and receive capabilities. A semiactive system does not have a transmitter and must depend on illumination from the attacking aircraft's radar.

However, it is doubtful that the two vendors will have delivered all the Lot 1 missiles by that date. Production of the full acquisition of 22,000 missiles for the Air Force and 7,000 for the Navy is slated to continue into the next century. Thus, the ability of the U.S. to produce the components for this system reflects important capabilities for the U.S. industrial base through the 1990s.

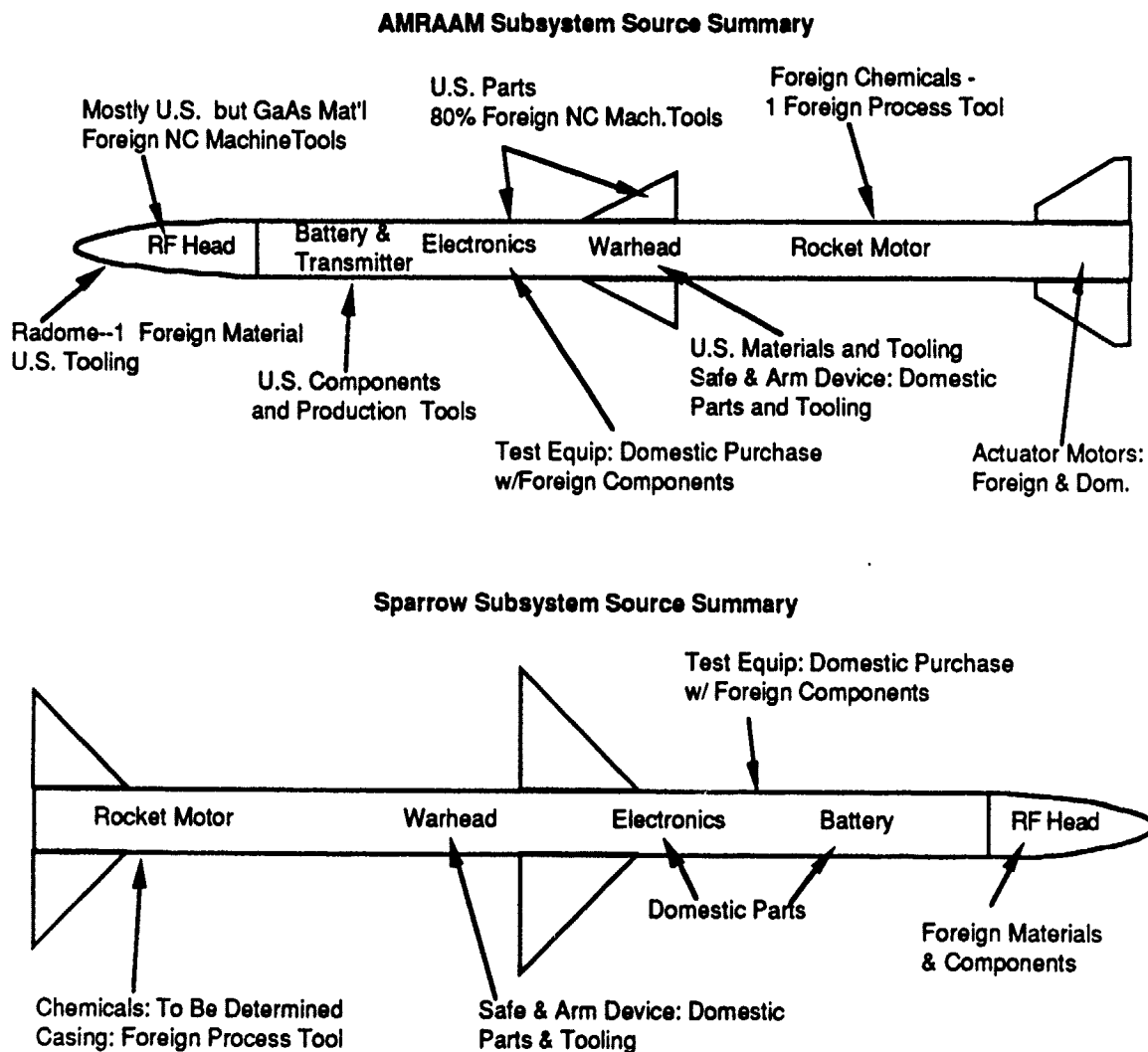
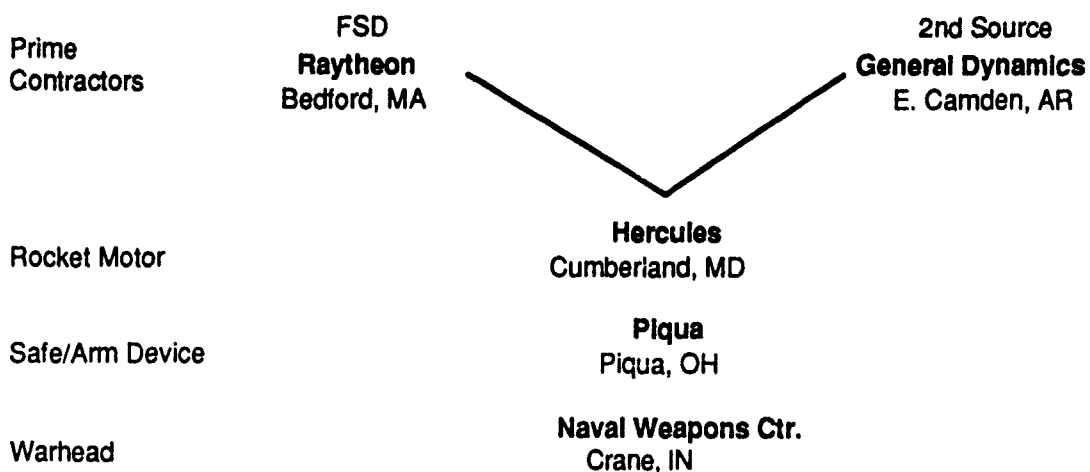


Figure B-III-1. Summary of Onshore- and Offshore-Sourced Items in the AIM-7 and AIM-120A.

AIM-7P SPARROW CONTRACTOR CHART



AIM-120A AMRAAM CONTRACTOR CHART

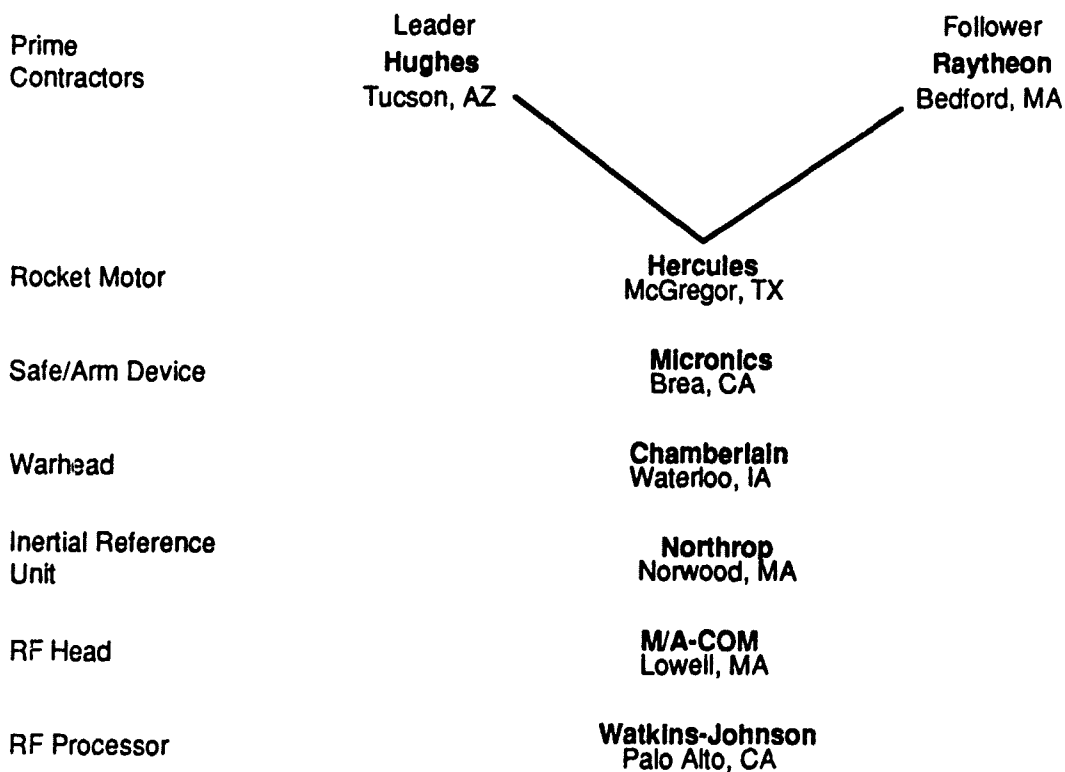


Figure B-III-2. Main Contractors for AIM-7 and AIM-120A.

B. SPECIAL STUDY METHODS

Data for this section was obtained in several ways. First, background data was obtained from standard references such as *Jane's All the World's Aircraft, 1988-89*, and *DMS Market Intelligence Service*. Next, we contacted the Joint Service Program Officer for AMRAAM, Brigadier General Charles E. Franklin, at Eglin Air Force Base, Florida. In addition, we contacted Captain Jesse Stewart, Program Manager, Air-to-Air Missiles, Naval Air Systems Command. With the help of General Franklin and Captain Stewart, we initiated contact with the prime contractors for AMRAAM (Hughes and Raytheon) and for Sparrow (Raytheon and General Dynamics). These companies proved to be extremely helpful in providing parts lists and names of important suppliers (selected by total dollar value and by estimated amounts of lead time to qualify an alternate source).

We then contacted the main suppliers of subsystems and parts for both missile systems. These include:

- Watkins-Johnson (AMRAAM), Palo Alto, CA
- Piqua Engineering Co. (Sparrow and, if qualified, AMRAAM), Piqua, OH
- Chamberlain Manufacturing (AMRAAM), Waterloo, IA
- Eagle Picher Manufacturing (AMRAAM and Sparrow), Joplin, MO
- Hercules (AMRAAM and Sparrow), McGregor, TX
- Northrop (AMRAAM and Sparrow), Dedham, MA
- M/A-COM (AMRAAM and Sparrow), Lowell, MA
- Corning Glass (AMRAAM and Sparrow), Corning, NY
- General Dynamics² (Sparrow), E. Camden, AR.

The manufacturers, with few exceptions, provided us with complete parts/suppliers lists. The data collected represents the major system contractors for the components in the AMRAAM and Sparrow. We were also afforded opportunities to observe manufacturing processes for systems which have long lead times for qualifying alternate suppliers. During these trips to manufacturing sites, we generally met with the program manager, a purchasing officer, and a program engineer. Our interviews were based on a standard list of questions about source location, reasons for use of particular sources, parts with long lead times, alternative sources, and types of problems that have driven U.S. source costs

² Teleconference contact.

up and reduced their competitiveness. These questions were intended to provide insight to the reasons for foreign sourcing done by U.S. firms within the defense acquisition process, the risks involved in foreign sourcing, and possibilities for reducing dependence.

Once this data was gathered, the parts lists were entered into a database in order to facilitate analysis.³ System manufacturers identified approximately one thousand third-tier firms that supply parts and components for the subsystems that the missiles comprise. Time did not permit visits to third-tier vendors, but we have obtained parts lists from some of these suppliers. In addition, we undertook a process to determine whether companies which supply parts for the systems are owned by foreign parent companies. This proved to be complex and time consuming.

C. LIMITATION OF SAMPLE SIZE

We obtained complete parts lists for the AMRAAM and the Sparrow. At the end of 1989 we had traced the major components to the third tier. To have a clear understanding of the full amount of foreign sourcing extant in these two systems, we attempted to get below this level and determine where fourth-tier suppliers are located, whence they obtain components and materials, and what type of technology is used to produce these components. For example, we knew where the firms that supply components to M/A-COM for the RF head for AMRAAM are located, but we did not know who their suppliers are and where they might be located. While we have only limited information on the fourth-tier level, it is reasonably certain that foreign sourcing increases substantially at this level, on the basis of information from the vendors, corroborated by the AMRAAM JSPO.

Large commercial distributors that supply many electronic components to primes and subcontractors present a potentially significant foreign sourcing problem. These distributors may utilize many different manufacturers for generic semiconductors and other products. For this study to be complete, we would also need to investigate further the supply sources of these large distributors.

³ Much of this data is proprietary information, and we agreed not to display it in full context.

II. FINDINGS

A. FOREIGN SOURCING

Study interviews were completed over a 6-week period. Because of the numerous vendors for the two different systems (some of whom produce components for both missiles), the findings are presented by major technology area: electronics, mechanical/structural, and chemical. Significant foreign-sourced items and their sources include:

AMRAAM actuator motors	Lucas Aerospace, U.K.
AMRAAM FETs and capacitors	Fujitsu, Japan
Rocket propellant chemical	Huls, Federal Republic of Germany
Raw materials (e.g., titanium, chromium)	Australia; South Africa
Numerically controlled (NC) machine tools	Japan; Federal Republic of Germany.

For AMRAAM, not less than five of the suppliers to Raytheon are foreign-owned but U.S.-based manufacturers. One supplier each to Raytheon and M/A-COM is located abroad. For Sparrow, only one of the firms supplying Raytheon is foreign owned. The number of foreign-owned firms is likely to be larger but requires further research to verify.

1. Electronics

The electronics in the guidance and control section of the missile are critical to the advanced capabilities of the newest generations of air-to-air weaponry. Both of these missiles incorporate a complete radar system in their airframes to track the target and guide the missile towards it. In the AMRAAM, the electronics allow the pilot to launch the missile and leave the area. The missile's guidance system first guides it to a point in space, and then energizes the radar transmitter in order to find and destroy the enemy aircraft. The guidance function is the major cost component of missiles. As Fig. B-III-3 indicates, 77 percent of the AMRAAM unit cost is for the guidance section, 34 percent being the Electronics Unit alone.⁴

⁴ AMRAAM APREP Decision Coordination Paper, pp. E2-16.

Sparrow's semiactive guidance system requires the pilot of the attacking aircraft to illuminate the target for the duration of the flight to the target. Because of its less sophisticated mission requirements, Sparrow's electronics suite is substantially less complex than AMRAAM's, yet it exhibits the same high degree of cost concentration in the electronic components. Of the 25 components Raytheon identified as primary cost drivers, accounting for 50 percent of the total purchased parts cost, 17 are electronic components.

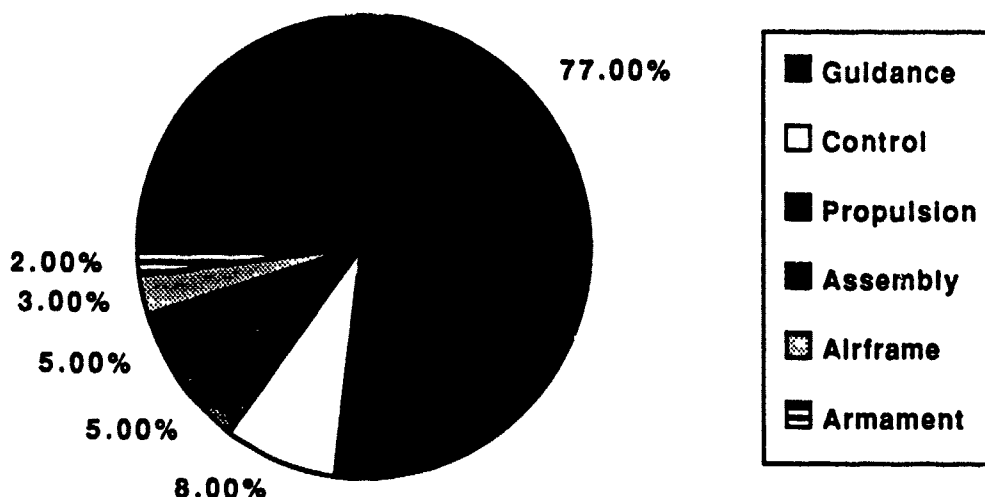


Figure B-III-3. AMRAAM Cost Distribution by Missile Section

Corporate management of the prime contractors advised us that, with the exception of the Lucas motor, there is no foreign content directly contracted into either missile. However, a representative of the AMRAAM JSPO found during a tour of one factory that numerous microelectronic components were labeled with offshore manufacturing locations. In fact, his informal survey of one circuit card revealed that the board contained 46 devices from 5 nations other than the U.S. His belief was that these devices were 883-screened devices; that is, commercial components tested to the MILSTD level. The quality assurance

personnel at the JSPO investigated this situation and discovered that for the devices questioned, the Defense Electronics Supply Center (DESC) allows foreign manufacture if the firm complies with the appropriate testing and qualification standards. Additionally, the manufacturer must grant on-site inspection rights. Our study has verified that similar situations exist in other electronic subsystems.

Foreign-produced commercial electronic components are generally selected because of limited domestic supply and substantial cost savings.⁵ Time constraints have precluded investigating the complete lower tier supplier base, but of the 10 fourth-tier electronic component companies we have been able to contact, all use some type of foreign-produced production equipment or commercially produced components which could be manufactured offshore. Commodity devices such as integrated circuits purchased from National Semiconductor or Harris generally have some foreign content, either material or labor. (See Appendix B, Annex II, for more information on these devices).

Another finding regarding microelectronics involves the manufacture of hybrid circuits. To produce these circuits, a manufacturer will often assemble specialized devices of his own manufacture with standard components purchased from distributors. Watkins-Johnson (WJ) makes hybrids for AMRAAM, and WJ personnel stated that they purchase unpackaged dice from the least expensive source to be incorporated into their devices, without regard to country of origin. Their perception is that the proprietary components of their own manufacture are the high-value-added devices and that the purchased circuits are commodities that could be reverse engineered, if necessary. The assembled device is then tested to the MILSTD level as though it were completely manufactured domestically. Since hybrid suppliers often bid these items under fixed-price contracts, their most important criterion is cost. To many firms, including WJ, cost is far more important than subcontractor vendor nationality, since they purchase thousands of microcircuits in a given year. Technology implications are important: if U.S. manufacturers are not in the business of developing these devices, they will lose the skills and personnel required to reenter production.

The raw materials required for microelectronics fabrication provide some offshore sourcing difficulties for the manufacturers. There are no competitively priced domestic sources of high-quality merchant gallium arsenide because demand in the U.S. is low relative to that in Japan. As a result, sources of the raw material are predominantly

⁵ See Appendix B, Annex II, Tables B-II-7, B-II-8.

Japanese firms such as Fujitsu. The gallium arsenide is delivered to Watkins-Johnson in the form of boules, or ingots. WJ slices the boules into wafers and completes the processing of the dice into completed circuits. If WJ were to lose its materials source, it would take at least 1 year to qualify a new source.

Many of the microcircuits for both missiles are packaged in ceramic chip carriers. These components are supplied by Kyocera, either from its plant in Japan or from its U.S. subsidiary in San Diego. We have been told by the JSPO that the quality of the U.S.-produced Kyocera products is not as high as that of the imported product. To date, no Sparrow or AMRAAM contractor has substantiated this claim. Kyocera-U.S. is said to import the raw materials for its packages from Japan.

Block upgrades, such as the AMRAAM Producibility Enhancement Program (APREP), have mixed effects on technology sourcing. On one hand, large-scale integration (LSI) microcircuits being incorporated into the APREP modifications eliminate the need for numerous devices with offshore sources, such as discrete semiconductors. Use of LSI devices also reduces the parts counts for the electronics section as a whole. One APREP project, the upgrading of the digital subsystem, will modify three existing subsystems, the input/output function, the data processor, and the filter processor. The project will incorporate very-large-scale integration (VLSI) gate arrays and will reduce the LSI gate arrays from 29 to 19. For the whole subsystem, it will reduce the parts count from 851 to 256, presumably including some currently sourced offshore. For M/A-COM, supplier of the radiofrequency head, the APREP program also has a sourcing disadvantage, however. The new monolithic microwave integrated circuits (MMICs) replacing older parts will require gallium arsenide substrates which must be imported from Germany. In this case, elimination of one offshore dependence has created another.

Almost all of the tests on the missile are performed by the primes and various subcontractors on automated test equipment (ATE). Without the capability of testing the guidance and control section, there would be no way to determine the functionality of the system. In 1986, Raytheon performed an extensive surge and mobilization study. This study found that "the most imposing impediment to rapidly increasing Sparrow missile production is the lack of factory special test equipment."⁶ Generally this equipment consists of commercial test components and computers configured to the needs of the

⁶ *Industrial Preparedness Study: Sparrow AIM/RIM-7M Mobilization*, Lowell, MA: Raytheon Missile Systems Division, pp. 6-8.

specific test. This category of equipment poses a significant foreign sourcing issue. Raytheon identified ATE equipment as a limiting factor to surge and mobilization levels. They contracted with Hewlett Packard (HP) to analyze the implications of attempting to ramp up production by more than 200 percent. Hewlett-Packard, one of the largest firms in the test equipment market, detailed the surge/mobilization effects for its products. HP found that many of their semiconductors are foreign-source dependent. Some of these were commodity devices where cost was the major decision criterion, but, more importantly, a large number were chosen because the foreign product was the only component available for a specific technology.⁷

2. Mechanical/Structural

Mechanical components of the two missiles include airframe, wings and fins, safe/arm devices, inertial reference unit, and radome. Each of these components is critical for the proper functioning of the missile. The primary offshore sourcing issue for this mechanical/structural area is one of raw materials. The stainless steel of the safe/arm device requires chromium mined in South Africa. The wings and fins are manufactured from titanium mined in Australia. In some cases new sources, which are not now economically viable, could be tapped, such as titanium sands in Florida. In other cases, however, there is no substitution possible, e.g., stainless steel cannot be made without chromium, and South Africa is by far the dominant supplier. The manufacture of the radome does not prove to be an exception to the issues described above. Corning makes the radome for AMRAAM for both Hughes and Raytheon from a material known as Pyroceram. Hughes purchases a completed product, while Raytheon purchases the casting and completes the grinding in its own facilities. The majority of the materials and all the manufacturing tools are domestic in origin. However, a specific sand, magnesite, is required for the radome and is procured from Mexico.

With the decline of the domestic numerically controlled (NC) machine tool industry, a significant issue for the manufacturers of mechanical components is how to procure the processing tools required. The highest precision automated cutting tools are often manufactured offshore. At Hughes, 80 percent by value of the production machining equipment for AMRAAM is Japanese. This equipment is required to produce the missile housing, fins and wings, and electronics chassis. Hughes management stated flatly that

⁷ *Industrial Preparedness Study: Sparrow AIM/RIM-7M Mobilization*, Lowell, MA: Raytheon Missile Systems Division, p. B-10.

U.S. vendors could not supply tools that would routinely maintain the levels of precision required for the manufacture of the missile, and estimated that it would take 3 to 5 years to qualify a domestic supplier. At M/A-COM, all production steps for the RF head are carried out in the U.S., but 100 percent of the tooling for precision machining is of Japanese origin. The quality of the Japanese machines is the deciding factor in this case also. In performing the Sparrow mobilization study, Raytheon concluded that to increase the capacity of the fabrication facility for mechanical components would require 26 new machine tools at a cost of \$9.4 million, of which 10 would be of Japanese origin.

Other than its requirement for the stainless steel, the safe/arm device does not have a foreign source difficulty. All manufacturing is performed domestically on U.S. equipment. At least one manufacturer prefers to support domestic machine tools manufacturers by eschewing the use of foreign production tools and processes. As a result, the firm has taken steps to ensure that its parts and tools remain U.S. sourced.

The JSPO for AMRAAM was aware of only a single case of offshore sourcing, the actuator motors. These components are multiple sourced, from Globe and Clifton Precision in the U.S. and Lucas Aerospace in the U.K. Cost was the decisive factor driving part of the procurement offshore. The actual contract quantities allotted to each manufacturer have varied from lot to lot, with cost as the sole selection factor.

3. Chemical

Chemical technology is a factor in three major components of the two missile systems: the warhead, the batteries, and the rocket motor. The warhead is made entirely of U.S. materials processed in the U.S. The warhead supplier has no foreign sourcing, but complains of scheduling delays because of domestic sole-source suppliers.

The thermal batteries designed into AMRAAM and currently being retrofitted to the Sparrow are manufactured by Eagle Picher in the U.S. The previous battery for the Sparrow was a silver/zinc type, and each required 7 ounces of pure silver. Both the raw materials and the high-tonnage presses necessary to manufacture the pressed-powder disks for the thermal battery are procured domestically. Thus neither the silver/zinc nor the thermal battery requires materials procured offshore.

The rocket motor has two areas involving foreign sourcing. First, the motor requires two constituent chemicals sourced from offshore. Isophorone diisocyanate (IPDI) is sold domestically by Thorson Chemical Corporation but is manufactured in Germany by

Huls. The key reason for its offshore production is that a chemical intermediate is phosgene gas, production of which is outlawed under U.S. environmental law. The other chemical component is hydroxy-terminated polybutadiene (HTPB), manufactured in the U.S. by Sartomer. This company was recently purchased by Atochem, a French concern. Current production capacity remains in the U.S. However, there are indications that Atochem will construct a plant to manufacture HTPB in France.

Second, one critical production machine, a flow-form machine to produce the motor cases, is purchased from Lifeld, a German company. The reason for the purchase was not immediately known; most likely it was economic. Similar machines are available from U.S. manufacturers, so it appears that dependence here on foreign technology is minor, as long as current sources remain viable.

4. Conclusions

Down to the third tier of suppliers, the U.S. is not irreversibly dependent on foreign sources to produce either AMRAAM or Sparrow. However, interruption of critical domestic and foreign sources could cause significant delays in production, particularly at the lower levels. The ability of the U.S. machine tool industry to meet the needs of defense system manufacturers has clearly deteriorated. Both AMRAAM and Sparrow rely on foreign machine tools for many of their metal-forming processes. While this diminished U.S. technology base does not affect the capability of defense manufacturers to meet the requirements of current systems and production schedules, it may prevent or delay the development and acquisition of next-generation weapon systems.

B. INFLUENCE OF LAWS, POLICIES, AND FINANCIAL PRACTICES

1. General Policies

Supplier decisions to use a foreign source are largely influenced by four broad considerations: governmental direction, quality, cost, and offset requirements. General policy directions on procurement from both DoD and Congress have reflected mutually exclusive desires to increase both overall domestic and foreign content of systems. Defense firms have been instructed both to "Buy American" and to use "Nunn monies"⁸ to cooperate in

⁸ See "NATO Cooperative R&D Amendment," *Congressional Record*, 22 May 1985, p. S.6756 and National Defense Authorization Act, Fiscal Year 1987, Public Law 99-661, Sections 1101, 1103 and 1105.

defense R&D and production with U.S. allies. Recently, conflicting demands have been somewhat ameliorated as more "Buy American" clauses are written into defense contracts in an effort to maintain important U.S. suppliers. However, Congressional desires to have allies share R&D costs remain an important complicating factor in defense procurement. These and other DoD procurement policies and practices, including administrative requirements and data rights appropriations, have adversely affected the economic situation of defense suppliers, which in turn has increased the opportunities for foreign suppliers of defense components.

Shifts in the overall procurement strategy have an important impact on U.S. manufacturers. It requires significant time, money, and patience to qualify suppliers for defense contracts. As a result, frequent shifts in the overall strategy, from "Buy American" to a push to cooperate more with allies, result in increased costs for U.S. contractors, and ultimately for U.S. weapon systems, as some shifts result in reduced U.S. domestic capabilities. Cooperative programs have proven to be effective but tend to increase costs if required after a system is already in production. In the Sparrow program, Japan has a license to manufacture Sparrow missiles. If the U.S. prime contractors were to manufacture the total production, the lower tier industrial base would be likely to accrue significant benefits from economies of scale.

2. DoD Requirements

A wide variety of DoD requirements, some contradictory, affect foreign sourcing of defense products. These include conflicting or highly restrictive manufacturing specifications, testing, second-sourcing, and paperwork requirements, all of which serve a purpose but also drive up the cost of doing business with DoD. For example, we found a situation in which a company is required to satisfy both corrosion and electromagnetic interference (EMI) requirements. Because of the details of the specification, if the corrosion requirement is met, then the EMI spec is compromised, and vice versa. In this particular instance, the customer was inflexible regarding the specifications; alternatives were not entertained. In another instance, the same manufacturer has run into problems with specifications 55110 and 28309A, which set different standards for printed wiring boards. Defense suppliers are forced to invest their own time and money to try to resolve these types of conflicts. As the costs rise in fixed-price contracts, fewer companies in the U.S. will be able to afford to do business with DoD, thus reducing the number of available domestic sources.

Specification differences among the services remain widespread. Economic production of key components has been complicated by unique specifications for each service. For example, despite the upcoming transition to DoD Standard 2000 (soldering), manufacturers are relatively certain that there will eventually be standards 2000.1, 2000.2, and 2000.3 for Army, Air Force, and Navy, because each service will be reluctant to relinquish autonomy over its own programs. Manufacturers absorb higher costs training people to implement and inspect each of the different soldering requirements. Meeting each service's specifications is a problem, especially on joint-service programs such as AMRAAM, which is likely to generate more conflicts, once it is approved for full-scale production, because of joint-service requirements.

Requirements for component testing sometimes have built-in redundancy that suppliers often consider unnecessary. For example, suppliers are required to perform a 100-percent test of semiconductors provided to Raytheon, and Raytheon is required to perform 100-percent testing upon receipt. Other firms face similar requirements. Additionally, many vendors insist that products that meet commercial standards are as good as, if not better than, those built to military specifications.

Requirements for second sources on selected missile parts can also drive costs higher. Prime contractors invest a great deal of time, effort, and money complying with requirements to qualify second sources. Qualifying a second source can be troublesome for a new system, particularly when the technology is complex and the size and timing of production lots are uncertain, as with AMRAAM. Second sourcing can also be a problem if it takes place late in the life of an older system that is likely to be replaced in the near future, such as Sparrow. Suppliers are acutely aware of how long it will take to recover invested capital in programs such as missiles, particularly when a production lot is split between two competing firms. In many instances, it is not economically feasible to require second sourcing.

Another significant problem for defense contractors is the issue of data rights. When new technologies are developed with governmental funding, the rights to the data are claimed by the government. This becomes an issue when contractor R&D funds are used in addition to government funds. Contractors claim that because the R&D was funded with corporate funds, the firm should own the data rights. A member of one SPO organization detailed the case of a vendor who developed a product specifically for a DoD application using corporate funds. DoD claimed the data rights and gave the design package to a

competitor for manufacturing competition. This vendor decided it was not worth the trouble to continue to market products to DoD and left the business.

These types of problems have greater implications for foreign sourcing than might appear on the surface. From 1982 through 1987, some 80,000-100,000 firms reportedly withdrew from offering manufactured products to DoD.⁹ There are many possible explanations for this decrease--mergers, buyouts, firms going out of business, changing needs of DoD--but our study encountered several firms who simply no longer found it profitable or worth the risks and effort to do business with DoD, and who are actively considering leaving the business.¹⁰ As the number of suppliers shrinks, domestic alternatives to foreign sourcing will grow even more limited, forcing DoD contractors to look overseas more often for potential suppliers.

3. DoD and SPO Audit Practices

Management of acquisition programs is, of necessity, complex. Because of severe performance requirements for many DoD systems, quality control must be tight. However, the manufacturers we worked with on this study, with one exception, expressed a feeling that the audit process was out of control.

Because the AMRAAM program has been a source of controversy, there has been a need to step up the auditing and quality control procedures. Two different DoD organizations perform audits of vendors supplying these missile systems--the Defense Contract Audit Agency (DCAA) and the Defense Contract Administration Services (DCAS). DCAA is responsible for auditing administrative and financial aspects of the contract. Its duty is to see that competitive procedures are complied with and that proper contracting methods are used. DCAS is responsible for certifying that the products meet the technical specifications quoted in the contract. Its personnel are the on-site DoD technical representatives.

Auditing procedures conducted by the DCAA serve to reveal if the manufacturer or supplier followed correct procedures and filled out the correct paperwork while working on a government contract. But other audits are also conducted by the program office and by

⁹ *Deterrence in Decay: The Future of the U.S. Defense Industrial Base*, Washington, D.C.: Center for Strategic and International Studies, 1989.

¹⁰ This finding is substantiated by Richard W. Stevenson, "Foreign Role Rises in Military Goods," *New York Times*, 23 October 1989, p. 1.

the services. The Hughes AMRAAM production facility in Tucson underwent four complete audits between April and September 1989. After such audits, companies generally spend roughly 20 hours answering questions and additional time attending, and preparing minutes on, any corrective-action meetings. Hughes personnel expressed concern for their smaller suppliers: although intensive audits cost Hughes time and money, they are particularly problematic for smaller firms which have less flexible production schedules and tighter manpower constraints.

Problems arise for suppliers when the quality of the DCAS personnel varies. Some suppliers interviewed have a good working relationship with their DCAS representative; others have alarming tales to tell regarding the inflexibility of DCAS. In cases where the DCAS representatives adopt an "us versus them" attitude, bureaucratic inflexibility works to the disadvantage of the manufacturers. In cases where the DCAS personnel work with the manufacturers to improve quality, both DoD and the manufacturers benefit.

4. Financial Developments

Many of the suppliers contacted for this work claimed to operate on a thin margin of profit. If a lot is delayed, they lose substantially in the short term. If a shipment is delayed for some reason beyond the contractor's control, the payment from the DoD is withheld. For small-to-medium-size firms this is a large financial burden. It is claimed that often the money withheld is never recovered. For production to remain onshore, defense manufacturers must be able both to produce a reliable, high-quality product and to turn a profit.

C. TRENDS AND DEVELOPMENTS

The IDA team encountered a number of significant trends occurring in the area of foreign sourcing. First, foreign commodity microelectronic components are being used at all levels but are most prevalent at the lower tiers of the production hierarchy. These items have been found to be commodity components purchased from commercial electronic distributors. Second, to produce mechanical and microelectronic components for the missile systems, manufacturers are becoming heavily reliant on foreign tooling. In the case of numerically controlled machine tools, for instance, 80 percent of Hughes' production machine shop is offshore sourced. Many makers of electronic devices also utilize foreign-sourced process tools for the manufacture of semiconductors. Finally, domestically owned production of certain raw and semifinished materials, such as gallium arsenide and

semiconductor ceramic packages, has become nonexistent. These trends affect the long-term capability of the U.S. industrial base to meet the needs of future defense systems.

III. CONCLUSIONS AND RECOMMENDATIONS

The foreign-sourcing situation does not appear to place the U.S. in an immediately vulnerable situation for either the Sparrow or the AMRAAM programs. The most significant technology-related foreign-source dependence identified appears common to most systems with substantial microelectronic subsystems--commodity semiconductors, ceramic packages, and advanced gallium arsenide (GaAs) materials. To the extent that short-term supply disruptions could be anticipated, stockpiling materials such as chromium and titanium and some semiconductors seems a feasible solution, but stockpiling ceramic packaging and GaAs appears to have significant technical limitations. The poorly developed U.S. production capabilities for ceramic packaging and GaAs are due more to the relatively small U.S. market for them than to any U.S. lack of access to the requisite technologies. Greater market interest in Japan caused the technology momentum to migrate and to provide the base for a now-dominant world market position. Since Japanese firms are now believed to outinvest the U.S. rather heavily in ceramics and gallium arsenide, the establishment of economically viable domestic commercial production would probably be a costly and lengthy process, but not a technologically insurmountable one. The same applies to semiconductor packaging and testing, which economic--not technology--considerations have attracted offshore. The other area of concern involves microelectronic production equipment and machine tools, especially numerically controlled and precision equipment. In these areas there appear to be growing indications of technological advantage shifting to foreign competitors, particularly Japanese companies.

It should not be assumed that foreign sourcing necessarily or in all cases involves greater risks or vulnerabilities than domestic sourcing. This study identified at least one significant example of a sourcing problem associated with domestic suppliers. That was the discovery by program managers that the safe-arm-fire (SAF) devices supplied for the Sparrow and AMRAAM and six other missile systems had not been tested according to requirements and, by one account, failed to function in a series of tests. The press reported in October 1989 that the Navy had suspended the supplier of the circuit boards found defective in these SAF devices, pending investigation. Arguably, the risks of relying on a

contractually required domestic supplier to test SAF devices would seem to involve as critical an aspect of missile performance as any part found dependent on foreign sourcing.

Economic advantages apparently continue to reside offshore in all three areas--microelectronic materials, packaging and testing, and production and process equipment--and have been abetted by growing foreign economies of scale and concentration of skill development. The revitalization and expansion of a U.S.-based commercial capability would be costly and take time for the training and qualification of suppliers, especially where the U.S. lags greatly in technology. Whether such cost and effort would be considered justified depends on judgments of the vulnerabilities and the importance of the individual system in question. Under present circumstances, the stability, prosperity, and cooperative relationships that exist in East Asia, where these production and process capabilities are now concentrated, do not pose predictable supply risks for these missiles. Although Sparrow and AMRAAM are not currently vulnerable, there is no way to guarantee that this condition will hold true in the future. The location of microelectronic component fabrication and mechanical and electronic equipment production and the retention of domestic research capabilities remain important issues,

There are two major ways in which the Office of the Secretary of Defense (OSD) can ameliorate within DoD the environment affecting foreign sourcing, both currently and for the future. First, it can develop and promulgate a coherent, explicit foreign technologies and components policy for DoD systems. OSD must clearly state what items or technology areas are important to keep on shore. Because the erosion of U.S. microelectronics, machine tool, and other precision equipment production capabilities may pose the greatest long-term risks for the development of future U.S. defense systems, OSD policy should particularly emphasize what capabilities appear essential to retain in the U.S. in this area. Second, because of situations involving materials such as ceramics and GaAs, as found in Sparrow and AMRAAM, OSD should develop an awareness of the importance to national security of the high-technology materials area and development of the domestic market for these materials. DARPA's technical expertise could provide important perspectives on what materials areas will be considered critical in the coming years. Because of its impact on commercial and international relations policies, this policy directive must be developed by OSD in cooperation with the Departments of Commerce and State.

- **The Office of the Secretary of Defense should develop and implement guidelines which provide a coherent, explicit foreign technologies and components policy for defense systems.**

Foreign-sourced tools for production are utilized throughout the manufacture and testing of DoD systems in virtually all technologies. Foreign penetration was most apparent in numerically controlled machine tools and components within Automated Test Equipment. *Though the U.S. industrial base possesses the tooling needed for current production requirements, the loss of process tool industries poses a significant threat to the development of future DoD systems.* The U.S. must maintain the capability to design and manufacture the equipment required for its unique requirements.

- **USD(A) should provide incentives for system vendors to cooperate with tool manufacturers in improving U.S. machine tool capabilities where they are currently lacking. In addition, USD(A) should consider and propose tax, financial, and contractual provisions that encourage accelerated modernization of vendor facilities to stimulate revitalization of the U.S. machine tool and robotics industries serving defense requirements.**

Foreign sourcing is affected by events outside DoD itself. This missile system study has noted that many laws and regulations regarding the use of foreign technology and components in defense systems are often contradictory. There appear to be two parallel sets of laws and regulations, one set promoting the use of offshore sources, for reasons such as cooperation with our allies and promotion of competition, and another set precluding the use of offshore-sourced components and technologies, mainly from concern about the integrity of the U.S. defense industrial and technology base. These conflicts are exacerbated by the fact that sourcing agreements often appeal to the Congress as promising, short-term policy solutions, while the consequences for weapon systems procurements persist over years, even decades. Thus, one set of guidelines will increase foreign content by encouraging the use of an offshore subcontractor, and another series of regulations may provide disincentives for the use of offshore-sourced components. However, where system and subsystem suppliers face intense cost pressures (for example, under fixed-price contracts), offshore component sources will be used even in the face of new guidelines aimed at protecting a decreasing defense industrial base. Program managers need an explicit, consistent policy regarding the use of offshore technology.

- **OSD, with assistance from DARPA, should work with the Congress to obtain a reconciliation and simplification of laws affecting foreign sourcing of technology.**

Many of the firms' representatives interviewed spoke of the problems of obtaining raw materials, from chromium to gallium arsenide. Some of the true raw material problems can be solved by a strategic material stockpiling. In many instances, stockpiling is not an adequate or effective guarantee of access to important technology. For example, the problems of semifinished materials are not dealt with so easily. Gallium arsenide (GaAs) is a good example. The fastest semiconductors and those that process radar signals require circuits made of GaAs. Here the difficulty is not one of the raw materials but the technology to produce from those materials an ingot of sufficient purity for the manufacture of semiconductors. This is not something that can easily be stockpiled. At this time, there is no merchant vendor of semiconductor-grade GaAs left in this country. Growing research areas such as that of high-speed semiconductors, which rely on new materials (like GaAs), are in need of support.

- **DARPA has the technical capabilities and need to develop a database and system for monitoring requirements for and competition in leading-edge critical technologies and materials required for the coming decades. No adequate database or monitoring system of this kind is currently available. Such a database is essential to provide OSD, DARPA, and the services information needed to formulate technology-related policies to support national security.**

Increasing attention has recently been paid to mergers and acquisitions of firms with high concentrations of defense business. During the Fairchild/Fujitsu acquisition arrangements, DoD became involved in an ad hoc manner. This missiles study has revealed that manufacturers and DoD do not automatically learn about, and they face serious obstacles in seeking out information on, ownership changes in important smaller defense companies. During the time this study was conducted, Sartomer Chemicals, the maker of the HTPB polymer matrix for many missiles, was acquired by a French firm, Atochem. This ownership change places control of one of the critical ingredients for tactical missiles out of the control of domestic commercial interests. A more thorough and systematic means is needed for alerting OSD and other appropriate officials of changes in ownership of defense-critical industries and of their impact on the industrial base.

- **The Office of Industrial Base Assessment of the Under Secretary of Defense for Acquisition has the charter to analyze the status of and the trends within the defense industrial base. This organization, combined with the Committee on Foreign Investment in the United States (CFIUS), should develop a more effective mechanism for monitoring mergers and acquisitions of defense-critical firms.**

Issues of foreign sourcing have an impact beyond the ability to produce in a crisis.

Simply put, the U.S. must retain a defense manufacturing base. Modern technologies develop very rapidly, and their effective application requires sufficient domestic R&D, engineering, and advanced manufacturing capabilities. As a result, stockpiling can only be a temporary solution. For essential domestic firms to maintain leading-edge technology and to continue competing for defense business, procurement practices must be changed to reduce the costs and risks of defense contractors enough to restore the returns in many areas of defense contracting to attractive levels. For this to occur, OSD must encourage USD(A), DCAS, and DCAA personnel to work *with* suppliers to reduce their costs and improve the defense business climate.

- **USD(A) should undertake a thorough review of the auditing procedures to reduce the burden of current cost accounting procedures.**
- **OSD, USD(A), DCAS, and DCAA should work to reduce the amount of other paperwork required of manufacturers.**
- **USD(A) should obtain assessments from suppliers and independent experts regarding defense system and service specifications and requirements considered most unnecessary, conflicting, or duplicative, with a view to their elimination or modification.**
- **USD(A)'s current effort to test the reliability and performance of U.S.-manufactured commercial parts relative to MILSPEC parts and allow substitution where performance is not hindered should have a high priority.**
- **USD(A) should reduce the total costs of U.S. defense manufacturers by increasing the size of buys of items with long shelf lives.**

APPENDIX B, ANNEX IV
HEAVY COMBAT VEHICLE ENGINES

Harold E. Bertrand

George Sorkin

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EXECUTIVE SUMMARY

Analysis of the M1A1 Main Battle Tank (MBT) engine (the AGT-1500) and the two Advanced Integrated Propulsion System (AIPS) engines (the LV100 gas turbine and the XA28 1500 hp diesel) identified only limited use of foreign-source technologies. While a few foreign parts and components were found in the AIPS engines, extensive foreign sourcing was identified in the machine tools for engine production. This foreign equipment sourcing shows an increasing trend;

- AGT-1500. There is no evidence of foreign sourcing of parts or components in the current M1A1 MBT AGT-1500 gas turbine engine. However, production is increasingly dependent on foreign-sourced machine tools.
- AIPS Development. A few foreign parts or systems are used in the AIPS developmental engines for either economic (cost) or business alliance reasons.¹ In the case of the recuperator (heat exchanger) for the LV100 gas turbine engine, the German firm of MTU developed a reliable engineering design and an associated manufacturing process to fabricate a recuperator that is considered by U.S. engineers to be a technological advancement over recuperators previously used in tank applications in the U.S. However, the U.S. is still considered the leader in recuperator technology development. In fact, GE and Textron Lycoming are evaluating U.S.-designed and U.S.-fabricated recuperators as candidates for replacing the MTU recuperator.
- AIPS Procurement. The AIPS development program contracts stipulate that the contractor is free to use any source for parts during the development phase but that domestic sources must be used during the production phase. When asked whether the contract phrasing allowed the contractors to use foreign sources, Tank-Automotive Command (TACOM) personnel said that TACOM did not want to restrict contractors in selecting technology that could be used during the development program, or to force them to buy from a more costly domestic supplier if a lower cost foreign supplier was available. TACOM noted that its contract with development contractors are fixed-price contracts and that costs in excess of TACOM funding must be borne by the contractors.

¹ AIPS engines are being developed for possible use in future tank and other heavy armored vehicles. Two AIPS-funded developmental engines will compete with a number of U.S. and foreign-industry-developed engines for possible application in the Heavy Force Modernization Program.

TACOM personnel emphasized, however, that they would enforce a "Buy-American" clause for the production contract. Therefore, for all parts sourced to foreign suppliers during the development program, the U.S. AIPS engine prime contractors must identify U.S. sources or have agreements with their foreign suppliers that U.S.-based manufacturing firms, either U.S.-owned (parts produced under license) or foreign-owned (existing or newly established firms), will produce the parts during the production phase. Implicit in this approach is that the volume of Heavy Force Modernization program vehicle procurements will justify the investments required for dedicated production facilities in the U.S. However, with budget cuts and a decreasing need for conventional forces in Europe, this assumption may eventually require revision.

- **Production Equipment.** Heavy dependence on foreign machine tools was evident in both the M1A1 and the planned AIPS engine production facilities. This is particularly true in grinding, machining, and turning (lathes and milling) machines. Reasons cited for foreign sourcing include lower cost, shorter delivery schedules, better responsiveness to procurement specifications service requirements, and better machine tool capabilities--usually expressed as ability to hold tolerances. U.S. military procurement contracts do not require that U.S. machine tools other other production equipment be used in the production of weapon systems.
- **Equipment Trend.** The study found an increasing trend in the use of foreign-made machine tools, particularly in the more costly, high-technology, numerically controlled grinding, milling, and multiaxis machining centers. In the case of Textron Lycoming, manufacturer of the AGT-1500 and codeveloper of the LV100 turbine engines, an analysis of machine tool purchases from 1985 to 1989 showed:
 - Almost 45 percent of a \$26 million tooling modernization program went for the purchase of foreign-made machine tools.
 - The average cost of its machine tools was \$179,000 for foreign-made versus \$41,000 for the domestic tools--an indicator of the greater technology sophistication embodied in the foreign-made tools.
 - The trend of foreign dominance in Textron Lycoming's acquisition of high-technology machine tools is increasing.

Conversations with the manufacturing managers of companies visited during this study reveal that foreign machine tool dominance is not restricted to the more costly, high-precision, numerically controlled (NC) machines. Their experience indicates that foreign manufacturers, primarily Japanese firms, are making a strong bid to take over the low end

of the U.S. machine tool market as well. Manufacturers also state that many parts of U.S.-labeled machines are also manufactured offshore and assembled in the United States. Over time a growing percentage of machine tools they buy to replace older equipment will come from offshore as foreign suppliers increase their market share.

The study found no foreign parts or components technologies for these engine systems that constitute a current defense system vulnerability. AIPS program requirements demand that all foreign-sourced technologies have a domestic production base. Such requirements extend prospects of nondependence on foreign sourcing into the coming generation of heavy vehicles. There is always the possibility that future defense budget cuts will reduce procurements below levels that justify required dedicated investments. However, trends toward increased reliance on foreign-sourced production equipment do give grounds for concern that, in a near-term (3-5 year) surge situation, continued erosion of U.S. machine tool and other production equipment sources could place U.S. manufacturers in a vulnerable position. While machine tools are available from a variety of European and Asian sources at present, current trends toward increased dominance by a single country could increase vulnerability over the coming decade even in the absence of a surge.

I. INTRODUCTION

A. SCOPE OF STUDY

1. General

The M1A1 Main Battle Tank (MBT) was selected as one of the weapon systems to be reviewed in IDA's study of U.S. defense system dependence on foreign technology because it is representative of mechanical systems used by DoD. It is also somewhat representative of future fighting vehicles. Because of time constraints and the magnitude of the tank, however, the authors decided to analyze one segment of the tank. Vetronics² were dismissed, since many of the technologies of concern were to be covered by our radar, flat-panel-display, and missile-system analyses. The fire control subsystem was rejected for the same reason, leaving the power train system as the most appealing option, since it relies on different production technology from the other systems. A tank engine, either turbine or diesel, is significantly different from those designed and manufactured for aviation, marine, and commercial vehicular applications. It is also in an area where foreign manufacturers have shared in technology advancements with the U.S. The power train system consists of the engine, the transmission, and the final drive system. The transmission and the final drive system were not considered here because their designs are similar to systems used in heavy construction equipment made in the U.S.

The tank engine system provides a unique look at mechanical parts and the machine tools used to produce them. The engine itself and its production tools are also broadly representative of engines in other motor-driven weapon systems. The study also included engines now being considered in the developmental Advanced Integrated Propulsion System (AIPS) program in order to ensure broad application to systems beyond the M1A1 and to identify any evidence of growth in dependence on foreign technology over time.

The significance of technology advances incorporated in tank engines is shown in Fig. B-IV-1. Commercial diesel engines have power-to-volume densities that approximate

² Vehicular electronic systems.

that of the 1790-2C engine (lower left-hand section of Fig. B-IV-1). The M1A1 and the next-generation tank power plants have power densities represented at the upper right-hand corner of the chart. The cost of developing and producing such high power-density engines is only justified for combat vehicle applications, because of the vehicle cost savings be realized by having a physically smaller engine housed in a costly vehicle. TACOM's position is that, given the numbers of combat vehicles required each year to maintain modern standing forces, the U.S. must be able to produce its own combat vehicles with U.S.-supplied technology and parts; if it cannot, then technology improvements and part supplies cannot be assured.

GENERAL DYNAMICS
Land Systems Division

BARE ENGINE COMPARISON

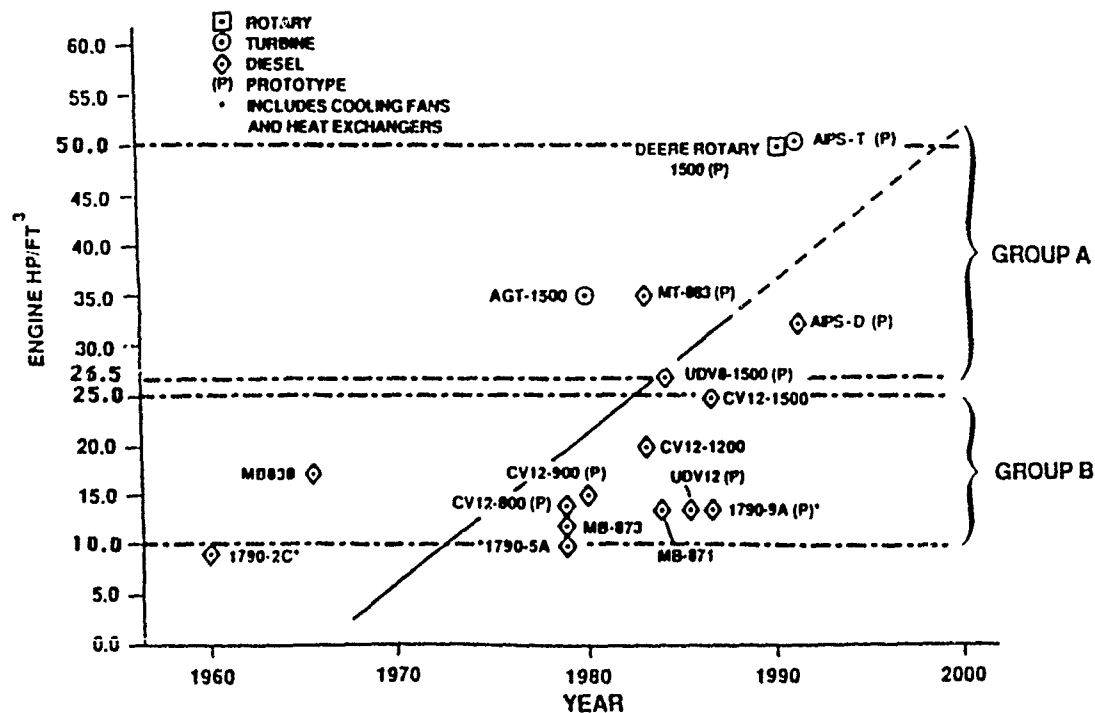


Figure B-IV-1. Tank Engine Technology Growth in Power Density.

2. Tank Engine Programs

a. Current M1A1 MBT Engine

The current M1A1 MBT is powered by the Textron Lycoming AGT-1500 gas turbine engine. The engine was designed and developed during the mid to late 1960s and was incorporated into the Army's MBT-70 procurement. This gas turbine was a complete departure from the previous predominant use of diesel engines in the U.S. tank fleet. In fact, this is the first use of a turbine in a combat vehicle by any country. The technology was all U.S. developed. Design advancements required for a turbine engine that had to live in a battlefield environment included:

- Higher than usual turbine reliability
- Low fuel consumption
- Ability to operate in a dusty environment with no degradation in power
- High power-to-weight and power-to-volume ratios.

These advancements in turn required advanced engineering designs and technology solutions for the key subsystems, such as the air-filtration, heat-exchanger (recuperator), and fuel-control systems. For the AGT-1500, the design, technology, components, and subsystems were 100 percent U.S. sourced.

b. Advanced Integrated Propulsion System (AIPS) Program

The Army's current armored vehicle forces, comprising the M1A1 MBT, the Combat Engineers Vehicle (CEV), the Armored Vehicle Launched Bridge (AVLB), and the Tank Recovery Vehicle (RCV), are not powered by a single engine, or even a single family of engines. Furthermore, the armor fleet no longer uses a common chassis because the current CEVs, AVLBs, and RCVs (referred to as ancillary vehicles) were procured as part of prior MBT procurement programs (the M60 and M48 MBTs).

The Army is now taking advantage of its Heavy Force Modernization (HFM) program to standardize the total armored force on a common chassis with a common power train. The AIPS program is an Army-funded tank engine development program intended to provide optional alternative tank engines, in addition to the AGT-1500 and other industry-developed engines, for use by industry in the development of HFM designs.

The AIPS program funded the development of two engines, a 1500 shp gas turbine, and a 1500 hp diesel. After an aggressive design competition, General Electric and

Textron Lycoming were selected for the full-scale development of their joint LV100 gas turbine engine design, and the Cummins Engine Company, Inc., was selected to develop its XAV28 1500 hp diesel engine. The current M1A1 AGT-1500 engine, along with the two AIPS engines, are the tank engines analyzed for evidence of foreign technology dependence.

B. STUDY METHODOLOGY

The study team used an interview process to collect the data necessary to perform the analysis on tank engines. Visits were made to the U.S. Army tank engine program offices at the Tank-Automotive Command (TACOM) in Detroit, and to each of the engine's prime contractors' facilities. The interview team was composed of one propulsion engineer and one manufacturing expert.

Plant visits followed a set agenda. First, technical discussions were held with the design staff to identify where foreign technology was incorporated into the engines and why. These were followed by discussions to identify outside purchases of parts and their suppliers. Finally, on-site surveys were made of the manufacturing shops where the current tank engine is produced and the AIPS engines would be produced to identify the extent of dependence on foreign manufacturing processes and tools.

Data requested of the Army program offices and contractors consisted of:

- Qualified Suppliers Lists for each engine
- Inventories of shop floor tools
- Work flow diagrams on the shop floor for each engine.

C. STUDY SAMPLE SIZE

The study sample represents the tank engine model currently in production in the U.S. for current U.S. Army Standard A assets. It does not include tank engines being built by Teledyne Continental Motors as spares for older M60 series MBTs. The sample also represents 100 percent of those engines developed under Army funding as candidates for the Heavy Force Modernization program. It does not include engines that may be proposed by defense firms in their HFM proposals that were either (1) developed by U.S. industries under industry-sponsored programs or (2) foreign-developed and would be produced in the U.S. firm, under license by a U.S. firm should the Army select an HFM design which incorporates a foreign-designed engine.

1

Visits were made to the engine prime contractors. While abundant anecdotal evidence was supplied by prime contractors that foreign dependence on machine tools extends to the second and third tiers of suppliers, more time would be required to make first-hand observations at the second and third tiers.

II. FINDINGS

A. FOREIGN SOURCING--ENGINES

Table B-IV-1 provides a summary of findings of foreign dependence for each of the tank engine programs analyzed. Details for each of the engine programs are presented in the text below.

Table B-IV-1. Summary of Findings From Studies--Tank Engines

Part/ Component	Assembly	Source	Reason	Delay for Alternative	Reasons for Delays
AGT-1500	Textron Lycoming				
Machine Tools	Milling, turning, grinding	FRG, France, Italy, JA, UK, Switz	Cost, del. qty, svc. availability	Indefinite	Development of technology base
LV100	GE--Textron				
Recuperator	Engine	FRG	Qty/rel/\$	2+ yrs	Development and qual. testing
Low-Pres.Turb.	Engine	FRG	Schedule/\$	2+ yrs	Development
Air Filter	Engine	FRG	Qty/rel/\$	2+ yrs	Development and qual. testing
Machine Tools	Same as AGT-1500	FRG, JA, etc.	Cost, etc.	Indefinite	Development of technology base
XAV28	Cummins Eng. Co.				
Injector solenoid	Engine	JA	Cost	1+ yr	Install prod. tooling
Head Bolts	Engine	FRG	Cost	No delay	N/A
Machine Tools	Same as AGT-1500	FRG, JA, etc.	Cost, etc.	Indefinite	Development of technology base

1. AGT-1500 Engine

Insofar as we could determine from discussions with prime contractors, there is no foreign sourcing of parts or subsystems for the current M1A1 MBT AGT-1500 gas turbine

engine at the prime level, or at subtier levels. The AGT-1500 was designed and developed in the 1960s by Textron Lycoming, Stratford, CT. The engine, which entered production in the early 1970s, is produced 100 percent from U.S.-supplied parts and technology.

2. LV100 Gas Turbine Engine

The LV100 was jointly designed and developed in the early 1980s by a joint team of General Electric, Lynn, MA, and Motoren-und-Turbinen Union (MTU), West Germany. Textron Lycoming was added to the team in 1987. As a result of MTU's being a team member, the LV100 incorporates foreign-designed and foreign-manufactured subsystems in three areas:

1. Recuperator (MTU, Germany)
2. Low-pressure turbine (MTU, Germany)
3. Powerpack cooling system (MTU, Germany).

The reasons given by GE for selecting MTU as a team member were:

- GE's longstanding cooperative business relationships with MTU
- New profile tube recuperator technology with high promise (higher reliability)
- MTU expertise in gas turbine and vehicular propulsion system design
- Lower cost and earlier delivery schedule for cooling system
- Potential for FRG/NATO market of vehicular propulsion systems.

For the recuperator, MTU came up with a superior engineering design representing an advancement in the technology, coupled to a matching manufacturing process to replace a U.S.-designed recuperator that has long plagued the AGT-1500 M1A1 MBT fleet because of its low mean time between failures. MTU's low-pressure turbine incorporates state-of-the-art technology, comparable to that available in the U.S., in its design and associated manufacturing processes. The MTU cooling system design was selected as part of the teaming agreement and not for technology reasons.

Even though recuperators represent a U.S.-developed technology, there were compelling technology and business reasons for signing MTU as a subcontractor, even if all production units are manufactured in the U.S. Business reasons (complementary capabilities of the two companies) dominated the selection of MTU for the low-pressure turbine and the powerpack cooling system. The largest number of U.S. tanks will be deployed to Europe. Historically, the recuperator, the cooling system, and the turbine hot

section are the engine systems generating the greatest amount of required maintenance. Support for the tank fleet, particularly repairs to or spares for these systems, is likely to be more competitive if provided by a Europe-based firm. In return, if MTU continues to power the FRG MBT, there should be opportunities for a *quid pro quo* where GE-Textron would supply parts for programs in which MTU is the prime contractor.

It must be noted that AIPS contractors were not restricted by their contracts from using foreign sources for parts or technology during the *development* phase of the contract. They are, however, contractually required to use American-built parts during the *production* phase.

3. XAV28 1500 hp Diesel Engine

The Cummins Engine Company, Inc. XAV28 1500 hp diesel engine, developed with the help of AIPS funding, incorporates two foreign-made parts in the development program engine. They are:

1. A fuel injector solenoid produced in Japan
2. A head bolt produced in Europe.

In both cases, the reason for using a foreign source was cost. In the case of the solenoid, the one U.S. supplier that bid on the procurement required \$750,000 for the necessary tooling to provide the development program quantities. The Japanese firm agreed to redesign a similar commercial solenoid to meet Cummins requirements at no cost and to bear any tooling modification costs required. In the case of the head bolt, where over 40 are required for each engine, the foreign-supplied bolt represents a saving of over \$3000 per engine. In both cases, there is no unique technology involved. It was simply a matter of a foreign supplier with a commercial product close to the XAV28 required part, who was willing to make the necessary modifications to the commercial part to satisfy the XAV28 requirement. In turn, the supplier was able to reflect in the cost quotations to Cummins the economies of scale resulting from production of a similar product for both commercial and defense applications.

One major benefit of the AIPS program is that Cummins has been able to design, develop, and build a diesel engine that incorporates state-of-the-art technology developed in the U.S. and elsewhere. Heretofore such technology has only been incorporated in European-designed diesel engines for armored vehicles, primarily the MTU883 diesel engine used in the FRG Leopard MBT.

B. FOREIGN SOURCING--MACHINE TOOLS

1. Foreign Dominance

According to the manufacturing engineering staffs at GE, Textron Lycoming, and Cummins, foreign suppliers now dominate the U.S. market for high-end milling, boring, grinding, and turning machine tools. This includes broaching and nonconventional drilling machines, multiaxis numerically controlled (NC) machine tools and machining centers, parallel-axis gear grinders, and jig grinding and boring machines. The U.S. tank and AIPS engine manufacturers stated that they are buying the foreign machine tools for the following reasons:

- In some cases, they are the only source available for a particular machine
- Higher quality machines (hold better tolerances, offer greater manufacturing repeatability)
- Lower cost
- Shorter delivery schedules
- More responsive to requirements to modify standard machine designs to meet purchaser's requirements
- Better after-market service
- Faster delivery of spare parts when needed.

Many U.S. companies still in business producing high-technology machine tools now depend heavily on foreign sources for technology and parts. For example, U.S. manufacturers of controllers for numerically controlled machines can no longer procure the microcircuits and dynamic random access memories (DRAMs) that go into the controllers from a domestic source. Tape and disk drives, which may carry the name of a domestic firm, are produced offshore. Castings and forgings for larger machines are produced offshore for cost reasons and are assembled into the final product by the domestic machine tool manufacturer. In many cases (large castings were given as an example), the domestic manufacturer has no economic choice but to go offshore; in others (gear and worm drives for precision) it is a matter of quality or of quality and cost combined. In reality, the domestic value added in U.S. machine tools is much less than is implied by the nameplates on equipment sold by U.S. suppliers.

2. Shrinking Domestic Supplier Base for High-Technology Machines

Many U.S. machine tool manufacturers in business during the 1950s and 1960s have gone out of business or have been acquired by other U.S. or foreign firms. Most notable in this category is the New England Machine Tool Company, a large company which produced multispindle milling machines and which recently went out of business. The erosion of the domestic machine tool base has continued into the 1980s and is dramatically illustrated by the data in Table B-IV-2 provided by the National Machine Tool Builders Association (NMTBA).

Table B-IV-2. Domestic Machine Tool Companies

Year	SIC 3521-- Metal Cutting	SIC 3542-- Metal Forming
1982	293	162
1987	245	126
% Change	-16%	-22%

A reason given for the above decline has been the success of foreign machine tool manufacturers in gaining U.S. market share. As an indicator of the success of foreign tool manufacturers in gaining access to the U.S. market, the NMTBA provided the data in Table B-IV-3 on total tool sales and total foreign tool sales in the U.S. to 1989.

Table B-IV-3. U.S. Machine Tool Purchases

Year	Total Purchases	Foreign Tool Purchases	% Foreign
1985	\$3.970B	\$1.689B	43%
1986	\$4.380B	\$2.217B	51%
1987	\$3.965B	\$1.969B	50%
1988	\$3.924B	\$2.032B	52%

The result is that some have abandoned some or all of their tool lines because of loss of sales, leaving the market for those tools open to foreign suppliers. This is particularly true in the case of numerically controlled, multiaxis machine tools and machining centers.

3. Foreign Dominance Expanding to Low-Technology Machines

While low-end machines that carry the names of American manufacturers can be purchased--such as lathes, drill presses, and grinders--many of these machines are now made overseas in Japan, Taiwan, and mainland China. In addition, tools bearing foreign brand names are rapidly replacing tools previously made in the U.S. Since market acceptance for the foreign-supplied tools has been good, U.S. suppliers are rapidly losing market share.

4. Foreign Suppliers Provide Better Services

Manufacturers interviewed report that most large foreign machine tool companies will absorb the engineering costs required to meet the specifications of the buyer. They are able to do this because of large economies of scale associated with market dominance.

Most foreign machine tool companies will place a team of company experts at the buyer's facility to oversee the machine tool installation and setup. In one case cited by industry for this study, the machine tool company's team was at the buyer's facility for almost 2 years. The services provided included design of modifications to the facility required to house the machine, installation, setup, and integration of the machine into the user's manufacturing process.

By contrast, most American machine tool companies have adopted the practice of charging for all engineering services required in a machine procurement. This was done to cut costs and become more competitive (reducing the indirect overhead load on off-the-shelf machine tool sales). In practice, defense industry sources tell us, it has actually worked against the American machine tool industry as their market share declined anyway, and they had fewer sales against which to amortize the uncovered indirect overhead costs. In after-market service, American companies typically propose service agreement contracts or assign the servicing requirements to independent service companies. Two of the engine companies asserted flatly that foreign tool suppliers are much more service oriented than their domestic counterparts.

5. Tax Laws and Cost of Capital Impact Domestic Deliveries

We were told during one of the interviews that the tax laws of many states work against the U.S. machine tool industry, but we were not able to quantify the impact. According to the Machinery and Allied Products Institute (MAPI), most states tax

companies on finished inventory on hand, not only that at the manufacturers but also that held by the distributor network. Moreover, high-cost tools sitting in a showroom or warehouse represent capital for which most domestic firms are paying high interest rates. In order to avoid taxes on finished inventory and high interest expenses, which can only be recovered by increasing the sales price of the equipment, domestic manufacturers tend not to build high-cost tools until an order is in hand. This results, ironically, in longer delivery schedules for most high-cost domestically produced machine tools than for those from foreign suppliers. While our analysis was not exhaustive, we could not find evidence of inventory taxes being charged the foreign toolmakers. IDA also found during its Defense Science Board study on microelectronics dependence that most foreign manufacturers had access to capital that cost far less than that available to domestic toolmakers.³ In addition, a White House Science Council study on microelectronics dependence showed that foreign R&D tax laws are more favorable than U.S. laws in that they encourage product research without impacting the cost of the current product line (100 percent expensing of R&D, first-year and rapidly accelerated expensing of facility investments).⁴

6. Current and Future Market Trends

One engine manufacturer surveyed during this study had recently completed a major (\$26 million) 5-year equipment modernization program. Our analysis of the program purchases shows that:

- Foreign-made machine tools represented only 15 percent of the 424 machine tools purchased under the plant modernization program
- However, these imports accounted for almost 45 percent of the modernization program's \$26 million cost
- The average value of the foreign machine tools purchased was \$179,000 versus an average \$41,000 for the domestic machine tools purchased.
- 38 percent of foreign equipment purchases was for tools costing more than \$200,000 each and accounted for 69 percent of all equipment purchases costing \$200,000 or more.

³ R.H. Van Atta and H.E. Bertrand, *The Decline of the U.S. Semiconductor Technology Base: Implications for the Department of Defense*, Institute for Defense Analyses, IDA Document D-644, September 1989.

⁴ E.E. David, *Report of the White House Science Council Panel on Semiconductors*, Office of Science and Technology Policy, Executive Office of the President, Washington, D.C., 1987.

Even after this multiyear machine tool modernization program, as much as 66 percent of its tools had an average age of 25 years or greater. Our analysis of its machine tool inventory after the plant modernization program was completed showed that:

- A major plant modernization costing more than \$26 million affected less than 12 percent of the total tool inventory
- 31 percent of the remaining tool inventory was purchased in the 1960s
- 33 percent of the remaining tool inventory was purchased in the 1950s
- 1.4 percent of the tools still in use had an average age of 45 years or more.

These data show that there remains a large number of tools that will most likely be replaced in this facility during the next decade. Given the trend of foreign takeover of the U.S. machine tool industry's market share, who will supply these tools as they need replacing?

It must be pointed out that the older machine tools still in use include presses, drill presses, bench grinders, welding units, paint sheds, simple lathes, and so on. They are all in excellent condition and are adequate for the jobs currently assigned to them. However, as manufacturing processes are changed, or as new materials are used in the manufacturing process and the time comes to replace these machines, given the rate that low-end machines are following the high-end machines offshore, "it seems unlikely that the trend to higher import dependence will be reversed."

C. INFLUENCE OF LAWS, POLICIES, AND FINANCIAL PRACTICES

1. Laws

a. State Laws

U.S. import laws allow U.S. manufacturers a tariff advantage in the domestic market when the imports exceed 35 percent of U.S. machine tool purchases in any given year. When triggered, tariff levels of 4.4-4.8 percent, with slightly higher tariffs on gear-making equipment, are applied to imports of foreign machine tools. However, at least some of the protective effect of the import tariffs is offset by state taxes on unsold inventory and by the less favorable R&D write-offs and longer investment depreciation schedules applicable to domestic as compared with foreign producers. While tax laws vary from state to state (according to MAPI), U.S. firms carrying a large inventory that enables

them to provide quick delivery upon receipt of an order are penalized by having to pay higher taxes, which are reflected in the sale price of equipment. Firms that wait for an order before they begin to build, according to engine manufacturers, suffer a delivery schedule penalty which on large machine tools can be measured in multiples of months, and in many cases, again according to industry interviews, this has forced the decision to go with the foreign source.

b. Federal Laws

Most foreign countries allow 100 percent expensing of R&D costs in the year incurred. The U.S. requires that R&D be capitalized and depreciated. The U.S. has equipment depreciation schedules tied to the useful life of equipment rather than the technologically useful life of the equipment.

2. Policies

There are no procurement policies directed at machine tool acquisitions by defense contractors. Concerned with making the best product possible and at the lowest possible cost, the contractor will buy the machine tools necessary from whatever source that will meet his specifications, schedule, and cost requirements. A contractor may be enjoined to "buy American" parts, components, and systems while performing on a defense procurement contract, but he is not so directed when it comes to the machine tools and other equipment required to produce goods for DoD.

3. Financial and Program Practices

DoD faces a dilemma when it comes to buying weapon systems. Since a new weapon system can take as long as 10 to 15 years to develop and deploy, DoD rightly attempts to ensure that the latest technologies will be incorporated at the time of the procurement. However, cutting-edge R&D is no longer the sole purview of U.S. institutions. Therefore, U.S. defense firms may seek out the best technology solutions not only within the U.S. but throughout the free world. Through licensing, joint ventures, acquisitions, mergers, and other business arrangements, they can guarantee access to those technologies for their company and DoD. Failure to use foreign technologies found to be more advanced than comparable U.S. technologies would be to compromise our national security policy of maintaining deterrence and strength through superior technology.

However, reliance on foreign technologies becomes a growing dilemma when the U.S. faces an extensive decline in its basic defense production capabilities. In the case of heavy vehicles, we are rapidly approaching a situation where we will not be able to produce the gas turbine and diesel engines developed with U.S. technology without machine tools purchased from abroad.

III. CONCLUSIONS AND RECOMMENDATIONS

A. SOURCING POLICIES

Problems concerning foreign sourcing have no single cure. An interesting dichotomy exists: defense systems should be producible with U.S. technology, but if foreign technology is better developed, it should not be ignored. Therefore arbitrary regulation of foreign technology use is not a solution.

- Equipment sourcing: DoD should make no changes in the procurement policies as they relate to foreign content. Do not add new policies to try to "fix" the problem by restricting access to foreign-source equipment.
- The Office of the Secretary of Defense should continue to encourage U.S. defense contractors to seek foreign technologies that lead our efforts but intensify efforts to maximize primary U.S. production of heavy combat engines. OSD is in a position to increase the competitiveness of U.S. manufacturers by promoting quality improvement programs, and more equitable R&D and tax treatment of defense suppliers.
- OSD should work with the Office of the U.S. Trade Representative toward the negotiation of "fair trading rules" in goods, with particular consideration of foreign subsidies, dumping, or other unfair practices that may adversely affect the U.S. machine tool, robotics, and other production equipment industries.

The above action can be taken in all DoD R&D funded programs to encourage the use of foreign-developed technology (technology importing). To have a consistent process that would capture usable foreign-developed technology, policy guidance on not restricting the use of foreign technology during the R&D phase of a program would have to be initiated at the USD(A) and DDR&E level, which would then direct the acquisition actions of the services.

B. DOD REQUIREMENTS, PRACTICES, PROGRAMS; FINANCIAL PRACTICES

- OSD, USD(A), and DARPA should allow IR&D funds to be spent on the development of manufacturing processes and machine tools. They should

require that products developed by this route only be licensed to U.S. firms and be built within the U.S.

This would require a change to the FAR and DAR governing allowable IR&D expenditures. The changes to the FAR and DAR would have to be initiated by OUSD(A) and implemented by Congress. Such changes usually are implemented as an amendment to the DoD budget.

- OSD should push for legislation to limit the investment tax credit to U.S.-built machine tools only, scaled to the U.S. content in the machine tools (excluding raw material).
- OSD should also push for legislation that allows accelerated depreciation of U.S.-made machine tools, again scaled to the American content in the tools (excluding raw material), and that allows a one-time expensing of U.S.-made (based on U.S. content) machine tools whose purchase price is \$10,000 or less.

A number of offices within OSD can take the lead regarding this issue: OUSD(A), OUSD(FM), OUSD(LA). Recommendations from the Defense Science Board through DDR&E can also prove helpful in moving such changes forward.

- DDR&E should study programs of foreign governments which have fostered domestic markets for robotics and other high-technology production equipment through capitalization of equipment leasing programs.

C. R&D IMPLICATIONS

- USD(A) should fund R&D, MANTECH, and IMIP programs for machine tool manufacturers without the prior requirement that they be defense contractors. MANTECH is currently limited to defense contractors for application to specific procurement programs. It should undertake such programs void of DoD specs and standards. Many of the finest machine tools now used in defense production come from offshore without the benefit of such specs and standards.

DARPA could initiate action through OUSD(A) to have policy guidance issued that would pass MANTECH and IMIP funding through from DoD prime contractors to machine tool companies. This would let DoD use the primes to manage the outside R&D efforts and to assist the tool companies with DoD reporting procedures. The R&D subject matter proposed by the contractor should, however, be approved by DARPA to avoid the possibility that the primes would only approve R&D programs for which the primes themselves saw a need. The end result of such a program should be the development of

improved classes of tools that would be more competitive with offshore suppliers and would also be available to DoD prime contractors.

- DARPA should fund R&D programs to develop superior manufacturing processes around U.S.-made machine tools. In programs where machine tools are found to be the pacing technology, it should fund R&D programs with the machine tool manufacturers.

DARPA could undertake a program to foster manufacturing process research on existing procurement programs under the current DARPA Initiative for Concurrent Engineering (DICE) program. This would provide the needed incentive to have current program manufacturers redesign parts of their current product along with the manufacturing process to reduce manufacturing time, production costs, scrappage and rework, and improve the overall quality and reliability of the end product. While this program would be very similar to the services' Value Engineering (VE) program, VE is not working because the services are not responding to the VE proposal evaluation process, even though industry has been enthusiastic about the program. In order to succeed, DARPA would have to negotiate an incentive program with the procuring agency that would reward the contractor for the benefits gained through such a program, even though the R&D may be sponsored by DARPA. The reason is that anything that reduces the cost of a DoD program also reduces the profit to the producing company.

D. RESPONDING TO SOURCING TRENDS

- DoD should not interfere in the dynamics of the market. The machine tool industry is a worldwide industry. The only way to influence the market is to offer an incentive for supporting the U.S. machine tool industry to those that conduct business with DoD. To do otherwise would probably hurt what industry remains here, and in the long run it would probably force DoD to pay a premium to get its products produced.

DoD is caught in the middle on any issue that tries to force a domestic manufacturer to buy U.S.-made machine tools. In some cases it would mean that DoD could not get the quality of end product required or desired. In other cases, it could mean that the end product would cost more because of the higher amortization costs of a more costly tool base. A DICE program directed at the machine tool industry would make sense but, because of a broader commercial application, might make better sense if it were funded by NIST or NSF.

E. AREAS FOR FURTHER STUDY

- OUSD(A) might initiate a case study of a major domestic machine tool company that has gone out of business to determine why, and to learn what factors could have made a difference in the survival of the company. Such a study should not be limited to an analysis of market share but should also include the business and management practices of the company. One candidate for such a study is the New England Machine Tool Company, which recently closed down operations.

OUSD(A) could undertake such a program and use it as the basis for developing a detailed machine tool R&D program. While the results would uncover factors that, if addressed, would involve many areas both inside and outside DoD, there has not been a systematic DoD approach to the problem to date. The end result would be a basis for a USD(A) program that eventually would help the defense industrial base to be less dependent on foreign sources.

- OUSD(A) can initiate a study to find out how foreign dependent the domestic machine toolmakers are for components that go into their end products. Two candidates for such a study are Cincinnati Milicon and Gleason Gear Grinding.

The depth of the problem of foreign dependence in the machine tool industry is really not well defined. During reviews of critical technologies for machine tools, it frequently becomes apparent that critical components in U.S.-made tools are procured offshore. This is the case for components of the controllers for numerically controlled (NC) machines. At the very least, a study of the problem would highlight the vulnerabilities of NC machines, which are thought to be critical U.S.-made products. More importantly, the results could identify areas that would lend themselves to DARPA-sponsored research.

- DARPA should continue the effort started in this substudy to explore the extent of foreign dependence for those supplying key production equipment to U.S. prime engine manufacturers. Although it was planned for the first phase of this study, time limitations precluded its execution.

The intent of this recommendation for further study would be to quantify the nature and extent of foreign dependence for tank engines.